1 of 2

AFGL-TR-81-0022

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DIGITAL IONOSPHERIC SOUNDING IN THE ARCTIC

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New ionogram observation techniques were applied at the Goose Bay Ionospheric Observatory (GBIO) in Newfoundland, Canada, and aboard AFGL's Airborne Ionospheric Observatory (AIO), using the Digisonde 128PS system. A receiving array of four crossed-loop antennas at GBIO enabled incidence angle and polarization measurements within the ionogram in addition to the Doppler observations. The Doppler information in the

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20. Abstract

propagation ionograms between the GBIO Digisonde and the moving AIO sounder facilitates the interpreting of different modes of propagation. Software for the AFGL CDC 6600 computer and for a microcomputer was developed for the processing of the digital ionograms. The identification of ordinary and extraordinary echoes in the Goose Bay ionograms greatly simplify the automatic processing of ionograms. Indeed, it became clear that for automatic ionogram trace identification the O and X tagging is a prerequisite. In support of the ESD 414L project an ionogram communicator (ICOM) was added to the GBIO Digisonde providing - via telephone lines - real-time ionogram printouts at the Over-The-Horizon Backscatter Experimental Radar System in Maine. Another Digisonde station was equipped and brought to operation in Keflavik, Iceland, to provide environmental data for the OTH radar operation.

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1.0 INTRODUCTION

This report is a summary of the effort performed by ULCAR from March 1978 to March 1980 in support of arctic ionospheric research at Goose Bay (Labrador), Keflavik (Iceland), the OTH Radar Site in Maine and AFGL's Flying Ionospheric Observatory. The Digisondes 128PS at Goose Bay and on board AFGL's KC135 aircraft have been updated and are operating to satisfaction. A Digisonde 128 was installed at Keflavik in Iceland and is recording good quality ionograms on magnetic tape and paper printout. A telephone link connects the Goose Bay Ionospheric Observatory and the Over-The-Horizon Radar Site in Maine to print in real time Goose Bay ionograms at the Radar Site, providing the ionospheric mid-point information when the radar operates in the northern half of its coverage area.

Computer software was developed for the processing of the tape recorded ionograms from the aircraft and from Goose Bay. For the automatic processing of Goose Bay ionograms we used the Geomonitor (Reinisch and Smith, 1976) data to extract the ionospheric parameters foF2, MUF(3000), ftEs and fmin. This Automatic Evaluation Program was successfully tested on some one thousand ionograms, and the results were published in Scientific Report No. 1 (Smith et al, 1979).

Routine evaluation of the hourly Goose Bay ionograms in terms of the standard URSI parameters was carried out. All parameters were coded onto punch cards for use by the Air Force and the World Data Center. Appendix A shows the graphic presentation of the monthly median values for 1977 and 1978.

2.0 DIGITAL SOUNDING SYSTEMS

To improve the diagnostic capabilities of the iono-
spheric sounding systems aboard AFCL's KC135 aircraft and at
the Goose Bay Ionospheric Observatory (GBIO), the digital
processing and control chassis were replaced by the Digisonde
128PS version. This new digital sounder (Bibl and Reinisch,
1978a) measures doppler frequencies as well as wave polariza-
tion and incidence angle if an adequate receiving antenna
array is available.

2.1 Goose Bay Ionospheric Observatory

The GBIO Digisonde system comprises: a new Digi-
sonde 128PS Processor chassis with ionospheric drift measure-
ment capabilities and on-line spectrum analysis, the analog
Receiver, Synthesizer and Translator chassis covering a fre-
quency range from 0.5 to 20 MHz, a new 2 × 4 loop Antenna
Switch, an additional antenna switch for 2 × 12 oblique re-
ceiving antennas, a vertical rhombic transmitter antenna, one
low-incidence-angle vertically polarized logarithmic periodic
antenna pointing to magnetic north, and a steerable horizon-
tally polarized log-periodic antenna, the latter three driven
by two Granger Pulse Transmitters. In addition to the local
Plasma Display and the double-ionogram printer, there are two
remote outputs: one connecting via dedicated telephone lines
to the Geomonitor in the "Receiver" building (building T831),
and the Ionogram Communicator (ICOM) chassis connecting via
RS-232C and modem interface to a dedicated telephone line for
remote printout of ionograms at the OTH site in Maine.

The System Description and Manual for the Digisonde
128PS (Bibl and Reinisch, 1978b) which was prepared for the
system operators explains the different modes of operating the
Digisonde. For routine ionogram operation, vertical and ob-

lique backscatter ionograms are alternated, initially at a
rate of 12 vertical and 12 backscatter ionograms per hour,
presently at 4 and 4 ionograms per hour. All amplitude values
in an ionogram are accompanied by 4-bit status words which
the Digisonde prints as a separate status ionogram (Figure 1).
Table 1 explains the meaning of these status words for the
different time periods since 1978. The so-called vertical
off-hour ionogram (A-program) actually scans three directions:
north-north-west, north-north-east (elevation 68°), and ver-
tical as indicated in Table 1. The hourly ionogram (C-program),
starting at one minute before the full hour, scans the mag-
netic meridian plane with elevation angles of 68°, 70° and
90°. The vertical rhombic antenna with a height of approxi-
mately 60 m is used for transmission. In June 1980 the trans-
mitter output was increased from 0.5 to 10 kW peak pulse
power. The 2 × 4 loop antenna receiving array provides the
right and left hand circular polarized signals to the Digi-
sonde's Antenna Switch which selects the O and X polarization
alternating from pulse to pulse. The 3 dB beamwidth of the
array is 11° for a frequency of 10 MHz. The first full side
lobe for this frequency occurs at a zenith angle of 37°.

The backscatter ionograms (B-program) use the linear
12-antenna array for reception and the fixed log-periodic an-
tenna for transmission in magnetic north direction. The
status words indicate the doppler frequencies from -14 to
+14 Hz for status numbers from 0 to 15. Peak transmitter
power is now also 10 kW. Figures 1a, b, c show a sequence
of vertical and backscatter ionograms demonstrating the three
types of ionograms.

On 3 July 1978 the Digisonde 128PS was brought to
full operation. During a very severe thunderstorm lightning
hit the equipment and destroyed a number of circuits in the
Processing Controller. The Controller was transported back

3

INTERPRETATION OF STATUS FOR GOOSE BAY IONOGRAMS

IONO.		STATUS		
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Tt	Z
Vertical Hourly 14 Jun 80	I/P	N_2	N_1	V_x	V_0	N_2	N_1	V_x	V_0	N_2	N_1	V_x	V_0	N_2	N_1	V_x	V_0	42	2
	S	-2	-2	-2	-2	-1	-1	-1	-1	+1	+1	+1	+1	+2	+2	+2	+2		
Vertical Off-Hour 14 Jun 80	I/P	O_2	G_2	V_x	V_0	O_2	G_2	V_x	V_0	O_2	G_2	V_x	V_0	O_2	G_2	V_x	V_0	42	7
	S	-2	-2	-2	-2	-1	-1	-1	-1	+1	+1	+1	+1	+2	+2	+2	+2		
Backscatter Nov 79	I/P	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	77	0
	S	-8	-7	-6	-5	-4	-3	-2	-1	+1	+2	+3	+4	+5	+6	+7	+8		
Vertical Hourly Jul 79	I/P	N_2	N_1	V_x	V_0	N_2	N_1	V_x	V_0	N_2	N_1	V_x	V_0	N_2	N_1	V_x	V_0	42	1
	S	-1	-2	-2	-2	-2	-2	-1	-2	+2	+2	+2	+2	+1	+2	+1	+2		
Vertical Off-Hour Jul 79	I/P	O_2	G_2	V_x	V_0	O_2	G_2	V_x	V_0	O_2	G_2	V_x	V_0	O_2	G_2	V_x	V_0	42	7
	S	-1	-2	-2	-2	-2	-2	-1	-2	+2	+2	+1	+2	+1	+2	+1	+2		
Backscatter 1978	I/P	*	D	V	N_2	*	D	V	N_2	*	D	V	N_2	*	D	V	N_2	45	6
	S	*	-1	-1	-1	*	-2	-2	-2	*	+1	+1	+1	*	+2	+2	+2		

I/P Incidence Angle and Polarization

N_2 Mag. North, 68° Elevation
N_1 Mag. North, 79° Elevation
O_2 Mag. 30° West, 68° Elevation
G_2 Mag. 30° East, 68° Elevation

S Spectrum, Relative Doppler Frequencies
V Vertical
V_0 Vertical, Ordinary Component
V_x Vertical, Extraordinary Component
D DAASM Array

22 Jul 80 Rei

Table 1

4
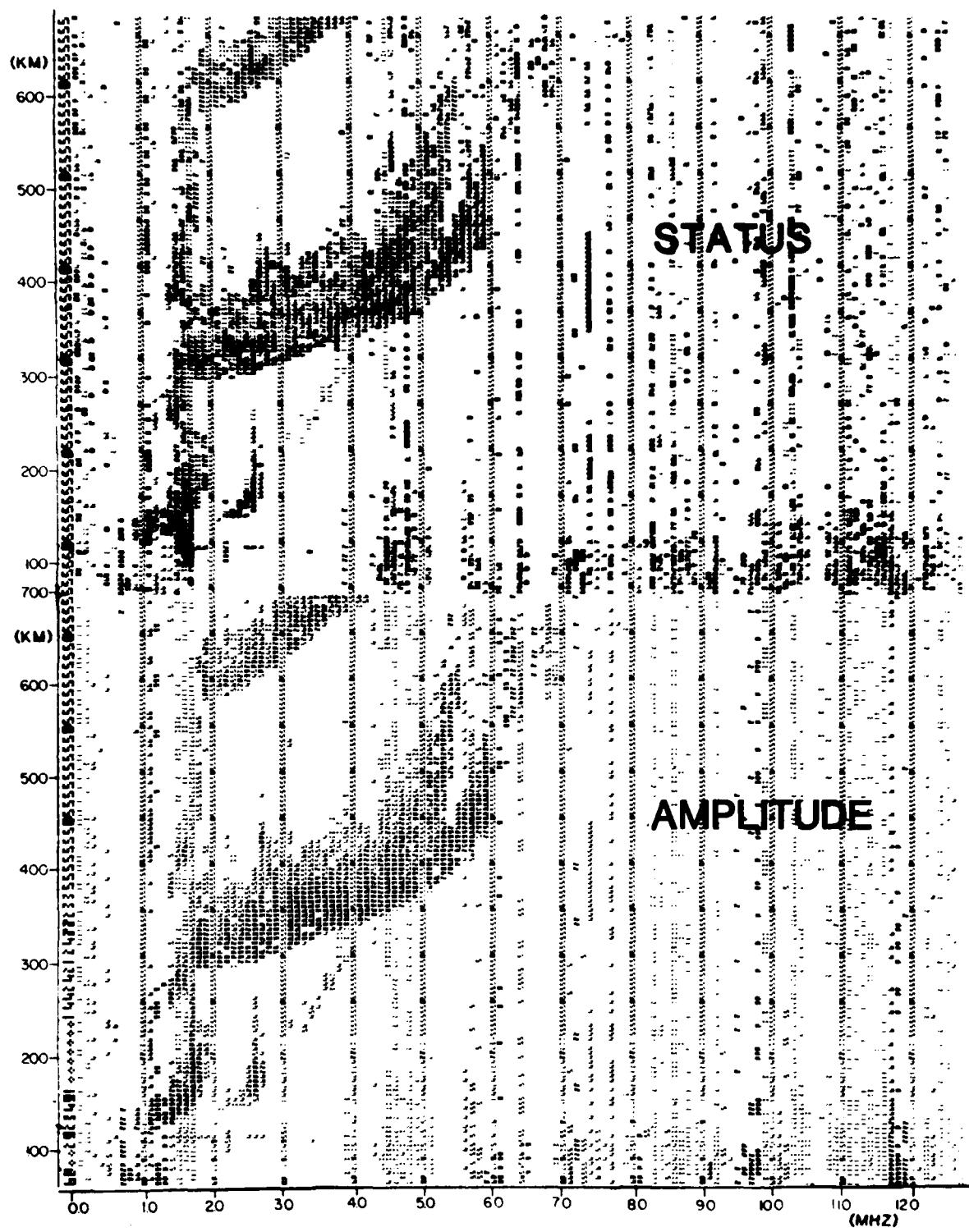
Figure 1a. Goose Bay Vertical Ionogram
29 JAN 1980 2349 AST
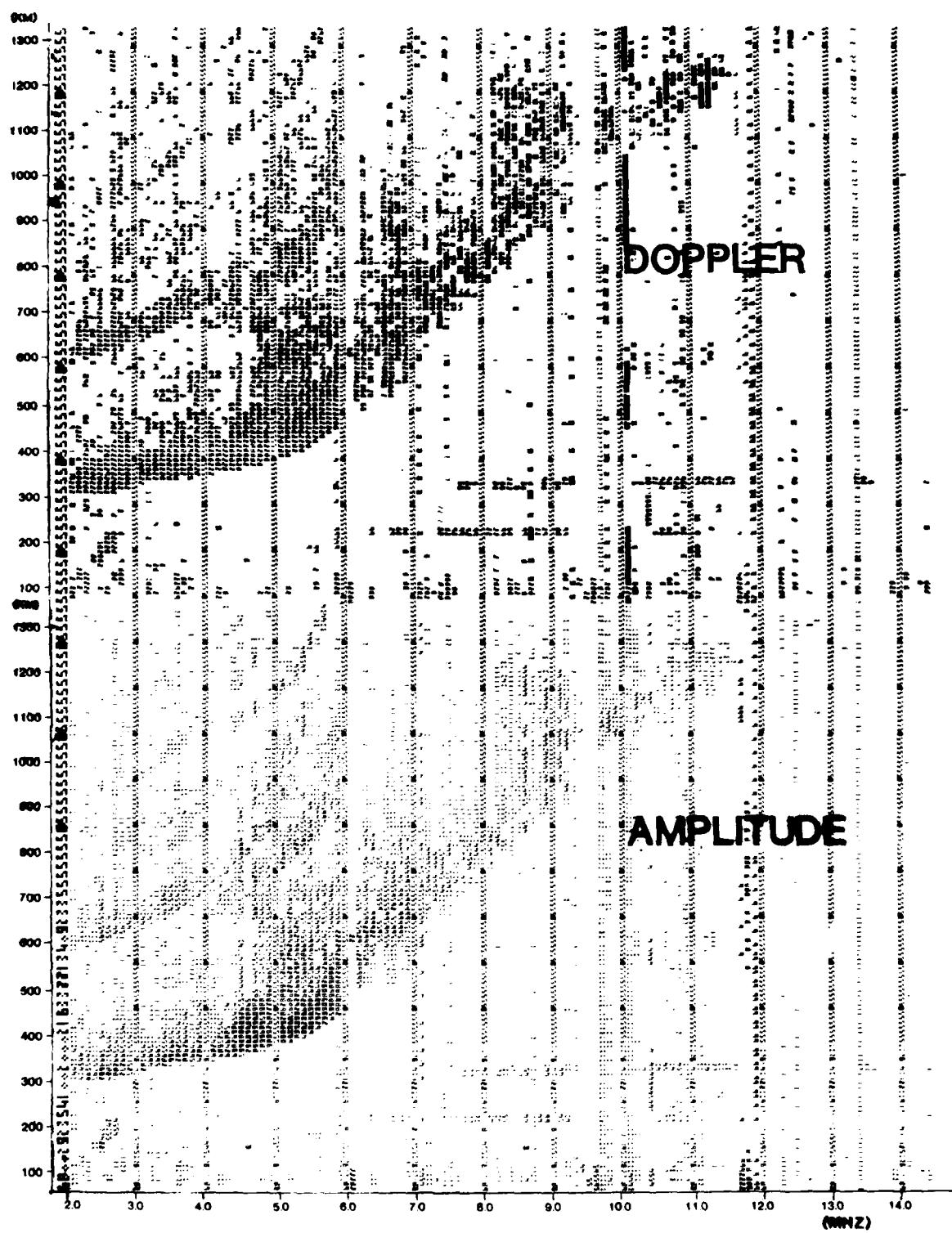
Figure 1b. Goose Bay Backscatter Ionogram
29 JAN 1980 2354 AST
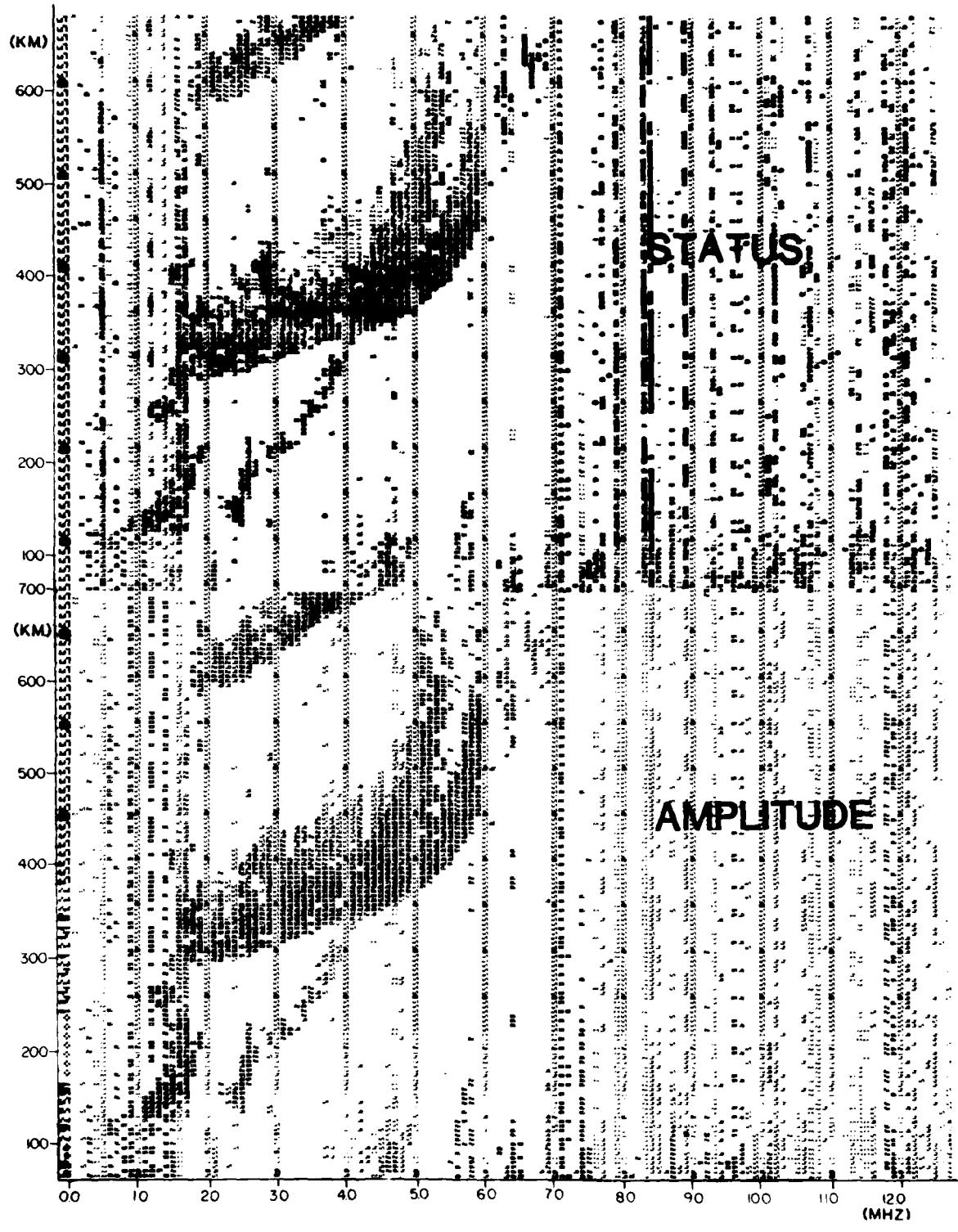
Figure 1c.   Goose Bay Vertical Ionogram, Hourly Program
29 JAN 1980 2359 AST

to ULCAR for repair. Since the old Digisonde 128 had been left in place to serve as an alternate it was used during the repair period. Components in the interface between the Digisonde and the Geomonitor were also destroyed. A new interface card, located in the digital chassis, was built and an additional interface buffer with separate power supply installed outside the main frame to avoid a repeat of this occurrence. Also the filtering on both sides of the telephone line has been redesigned and rebuilt to discharge any static electricity on either end of the line and to separate the signals from the large differential AC between the two stations caused by the poor grounding conditions in the sandy soil.

The Digisonde 128PS chassis was updated to include the capability of suppressing the X-echoes in the on-line and Geomonitor outputs and to be able to produce double ionograms with amplitude on one frame and the status on the other, in addition to the split screen capability. Figure 2a shows an amplitude ionogram on top and the respective status ionogram on the bottom. Printing of X-polarized echoes was suppressed in this ionogram except during small frequency intervals marked by an "X". Suppression of the X-echoes is programmable and was deactivated during the "X" intervals to demonstrate the effectiveness. In this 1978 ionogram the status numbers are even for the O-echoes, and odd for the X-echoes. Figure 2b illustrates the optically weighted number font that had previously been developed for the Digisonde ionograms (Bibl et al, 1971).

2.2 Geomonitor Interface

A special interface card was designed and built at ULCAR for interfacing the Processing Controller to the Geomonitor. This new card, GEOMON MII 26, simulates the data rate and format of the Memory of the old Digisonde 128. For
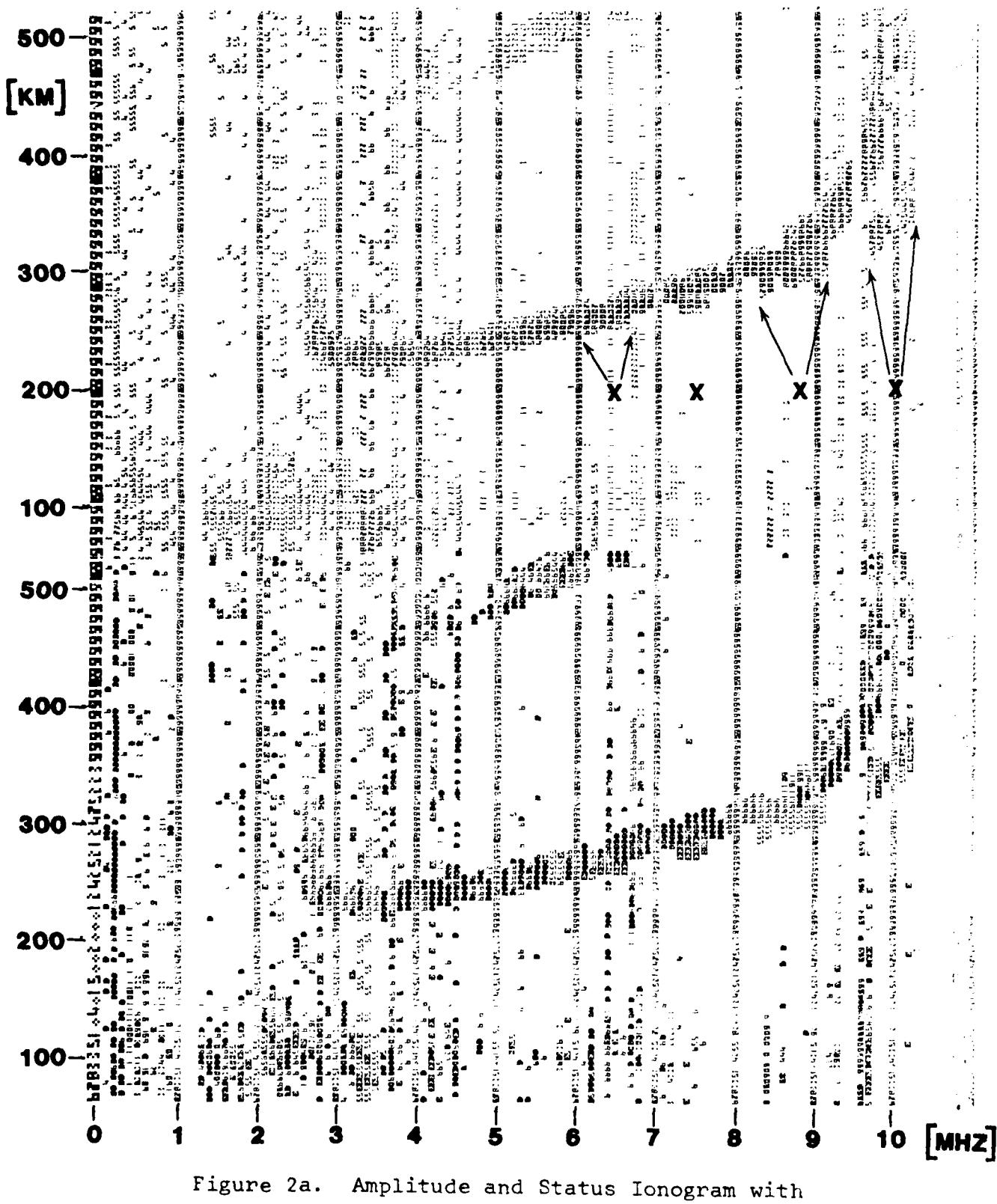
Figure 2a. Amplitude and Status Ionogram with
Switched Suppression of X-Polarization

9
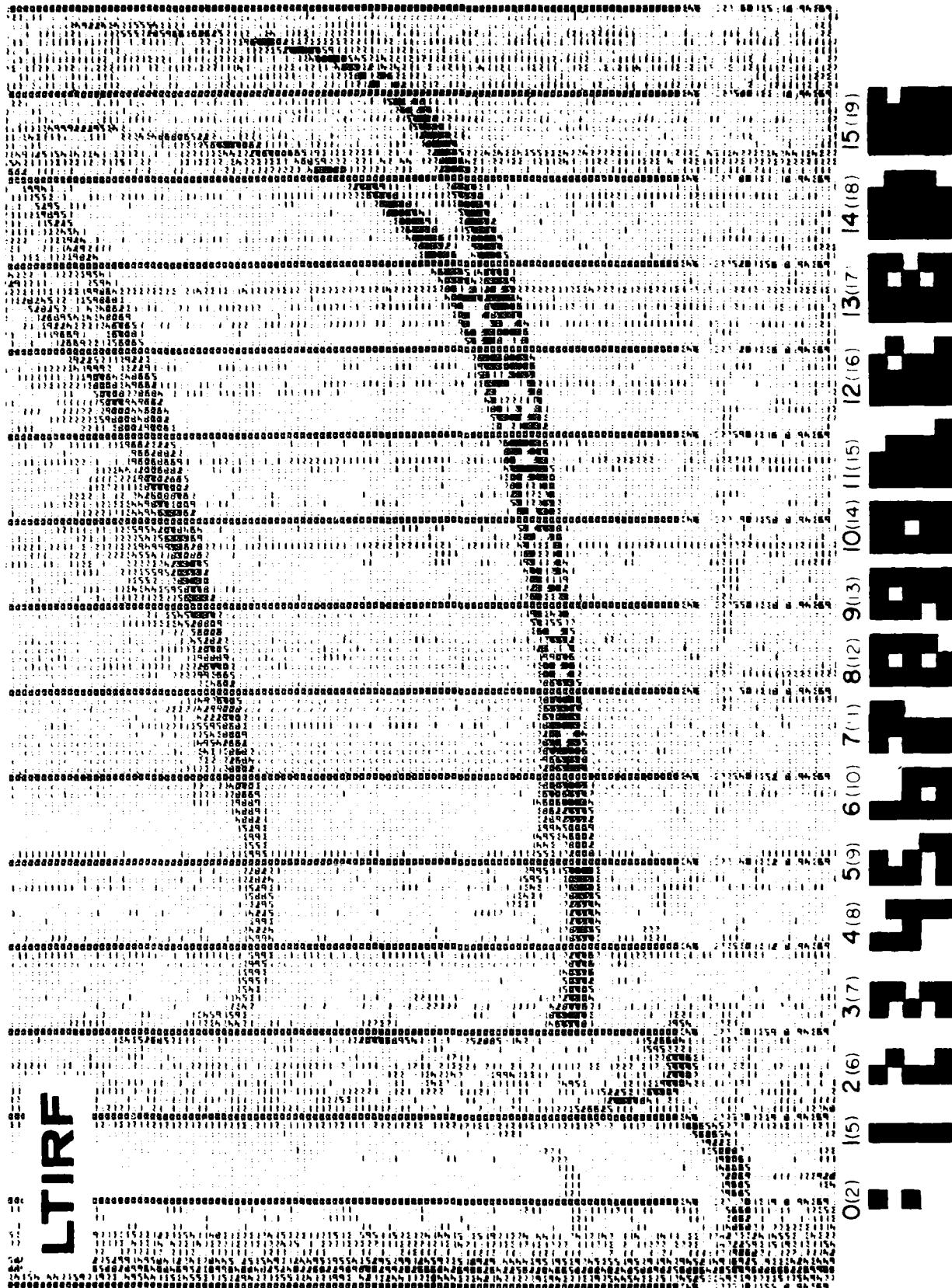
DIGIONOGRAM PRODUCED IN REAL TIME WITH DIGISONDE 128

MAGNITUDE OF COMPLEX AMPLITUDE AS A FUNCTION OF FREQUENCY

AND RANGE PRINTED WITH ONLINE PRINTER

Figure 2b

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each ionogram frequency a group of 216 six-bit characters is outputted at a rate of 500 Hz. The first 24 characters are the preface, which is followed by 128 × 1.5 data characters. The two highest bits of the first preface character (Station Identifier) are set equal to 1, signalling to the Geomonitor that the arriving data are coming from the new Processing Controller. The 32-character preface of the Processing Controller is compressed on GEOMON to 24 characters as indicated in Table 2. Most characters in the Processing Controller preface are BCD (0-9 representation). To keep a consistent preface length of 24 for the Geomonitor several characters have been combined. The 2LSB of the first character are placed in the 2MSB of the new 6-bit word. For example in combining Bb the new compressed character has the configuration

bit

32	B(2)
16	B(1)
8	b(8)
4	b(4)
2	b(2)
1	b(1)

A new subroutine was added to the Geomonitor firmware, so that the Geomonitor can now be connected to the new Processing Controller or to the old Memory. Both operations were successfully demonstrated.

2.3 Geomonitor

After having been damaged by lightning the Geomonitor had been shipped to ULCAR. The necessary repairs were performed and the following software changes were made: (1) a coding error in the NOISE algorithm was eliminated, and (2) the number of processed frequencies was increased from 128 to 170 frequencies to accommodate the high critical frequencies

CHARACTER NO. 128PS	GEOMON	SYMBOL	FUNCTION
1	1	V	Station Id.
2 3	2 3	Y y	YEAR
4 5 6	4 5 6	Δ D d	DAY
7 8	7 8	H h	HOUR
9 10	9 10	M m	MINUTE
11 12	11 12	S s	SECOND
13 14 15 16	13 14	Γ F f a	FREQUENCY
17 18	15	B b	Beginning Frequency

CHARACTER NO. 128PS	GEOMON	SYMBOL	FUNCTION
19 20	16	E e	End Frequency
21	17	R	Rep. Rate
22		W	Pulse Width
23 24	18 19	T t	Task
25		Q	Freq. Incr.
26	20	N	Integr. Number
27		X	Phase Code
28	21	Z	Azimuth
29	22	K	Range Incr.
30	23	J	Range Start
31		G	Gain
32	24	G'	Mod. Gain

7805 080 Rei

Table 2. Modified Preface for Geomonitor

12

of the F layer experienced during the years of high sunspot
numbers. The latter change increased the amount of output
data from 2340 to 3072 six-bit characters. A hardware modifi-
cation in the Geomonitor was necessary for the new magnetic
tape record length of 3072 bytes. This record length applies
to both ionogram and geophysical data. In the latter case
only the first 2340 bytes contain meaningful data. Table 3
shows the magnetic tape recording format for the ionogram
data.

A five position rotary switch, mounted on the Geo-
monitor front panel, selects the number of ionograms that are
printed on the Versatec printer, and the type of ionogram, i.e.
reconstituted or raw (dynamically cleaned) ionograms. The
Plasma Display is always activated and the rotary switch
merely selects cleaned or reconstituted ionograms. Table 4
lists the available options.

2.4   Ionogram Communicator

ULCAR has submitted to AFGL a System Description and
Manual of the Remote Ionogram Communicator (Smith et al, 1979).
This report gives a detailed description of the ICOM system.
Since its installation in July 1979 the remote printout system
is working very reliably, communicating the ionogram informa-
tion from Goose Bay to the Maine OTH Receiver Site.

Figure 3 is the ICOM flow chart which describes the
priorities of the system. In the event of a failure in the
system, several modes of operation are available to isolate
the device producing the problem. In the block diagram, Fig-
ure 4, the progression of data is shown.

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Character No.	Explanation
1 - 12	Header
13 - 36	Modified 128PS Preface
37 - 1396	{N, G, AE1, AE2, AF1, AF2, AF3, AF4} × 170 Frequencies
1397 - 2926	{HE1, HE2, DE, HF1, HF1/E1, HF2, HF3, HF4, DF} × 170 Frequencies
2927 - 3054	{IH} × 128 Range Bins
3055 - 3072	Not Used

Table 3. Geomonitor Ionogram Data Tape Format

Rot. Switch	Cleaned Ionograms Iono. Times [min]	Reconstituted Ionograms Iono. Times [min]
1	59, 04	
2	59, 14, 29, 44 (all vert.)	
3	All Ionograms	
4		All Ionograms
5		59, 04

Table 4. Geomonitor Ionogram Printout

15
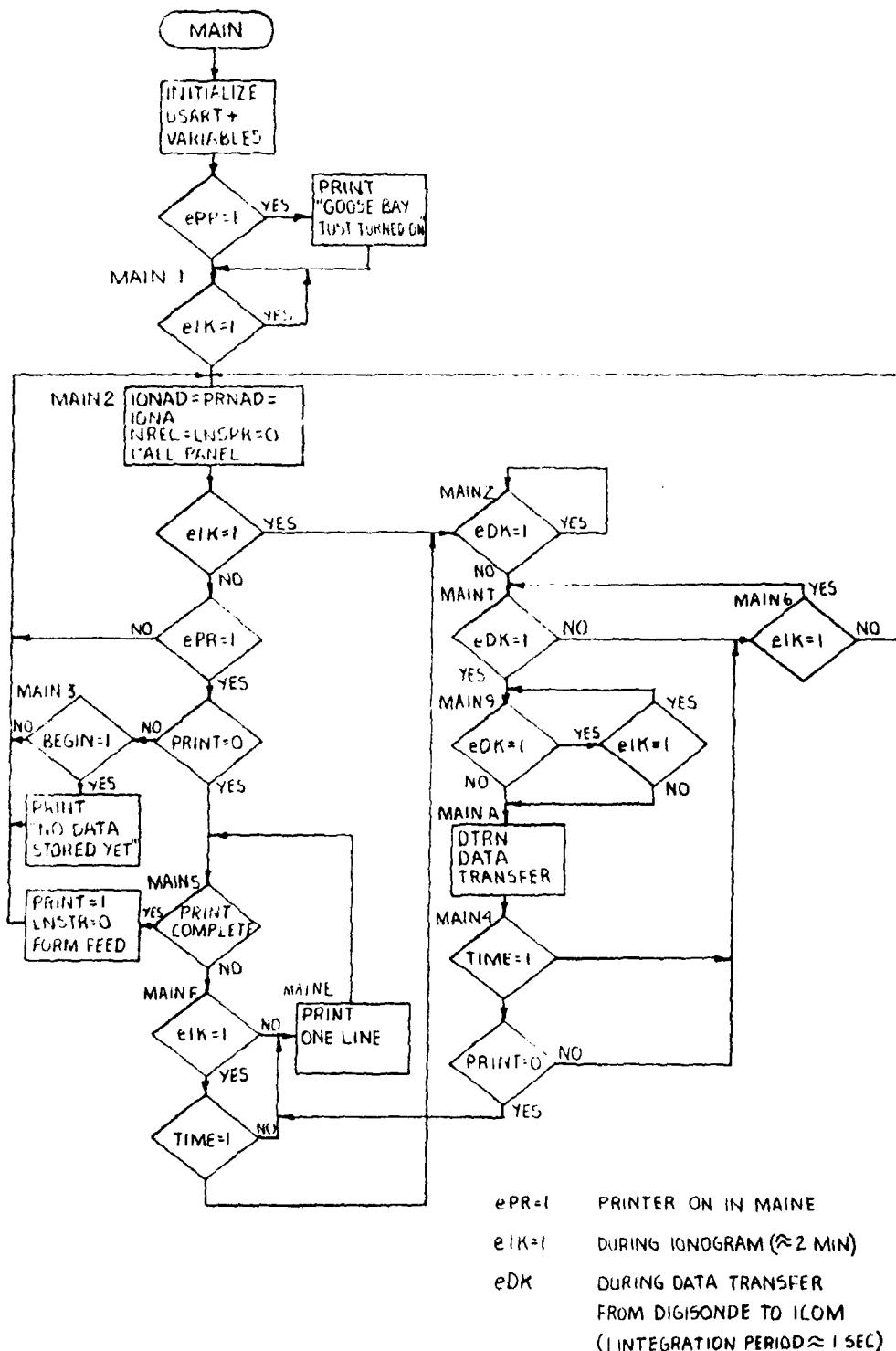
Figure 3. Main Flowchart ICOM 7810 005
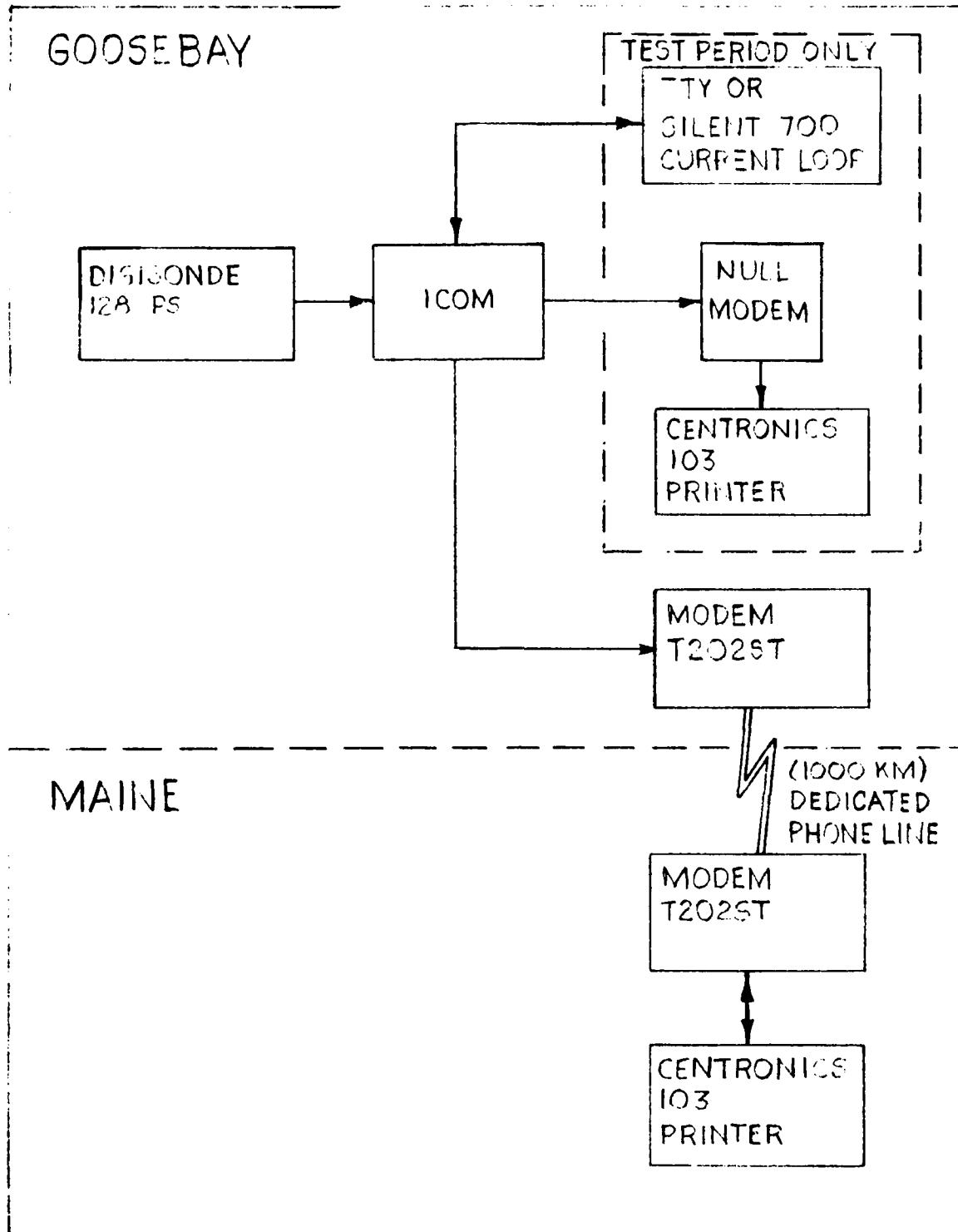
Figure 4.   ICOM Block Diagram   7810 005

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2.4.1 ICOM→TTY

In the ICOM a sample set of data is stored in PROM (Programmable Read Only Memory). This enables a check of the static shift register (SR) hardware and the programming within the ICOM independent of the Digisonde. The output is the PROM ionogram which is printed on the Silent 700 after processing for noise and X-trace identification. The flow of data is:

$$\text{PROM} \rightarrow \text{SR} \rightarrow \begin{array}{c} \text{RAM} \\ \text{ICOM PROGRAM} \end{array} \rightarrow \begin{array}{c} \text{RS232} \\ \text{CURRENT} \\ \text{LOOP} \end{array} \rightarrow \text{SILENT 700}$$

2.4.2 DIGISONDE→ICOM→TTY

The next step in testing the system is DIGISONDE→ICOM. Here we interface to the Digisonde using a 7-bit parallel data stream. The Digisonde 128PS provides a system calibration ionogram which is processed and displayed on the Silent 700. Only after completion of the ionogram (end of ionogram sensed) is the entire ionogram sent to the print device. Ionogram time is always tested: only ionograms recorded at times specified by the front panel SELECT switch are chosen for transfer to the printer. Figure 5 shows part of a calibration ionogram scanning from 2 to 12 MHz.

2.4.3 CENTRONICS (self test)

An important feature of ICOM is the ability to isolate each device for troubleshooting. The Centronics printer has been modified to display the Opti-Font character set across 132 columns in a self test mode. This is accomplished by pushing

a) ON button

b) self test switch under front cover to test (alert light indicates self test is on)

Figure 5. Digisonde-ICOM-Silent 700 Calibration Ionogram

c)   SELECT button

d)   FORMS OVERRIDE button.

If the FORMS OVERRIDE button is pushed using a momentary action
the printer displays the font-equivalent of 0 - 15. If the
FORMS OVERRIDE button is held down, the font equivalent of
16 - 31 is displayed. The numbers 16 - 31 are the same as the
0 - 15 numbers except for an underlining of the numbers. This
underlining technique can be used to emphasize the ordinary
or the vertical echoes. Figure 6 is an example of the display.

After final testing at ULCAR the ICOM was installed
at the Goose Bay Ionospheric Observatory in the first half of
July 1979. At the same time the modified Centronics printer
with Opti-Font^R was installed at the USAF's Experimental OTH
Radar System in Maine. The ICOM system was adapted to the
Government supplied modems and routine transmission of Goose
Bay ionograms to Maine began about 20 July 1979. An ICOM
transmitted ionogram as printed in Maine is shown in Figure 7;
here the X-echoes are suppressed and the vertical echoes
underlined.

2.5 Antenna Switch

A new Antenna Switch was built, tested and installed
at Goose Bay, interfacing the 2 × 4 receiving loops and the
linear 12-antenna array to the Digisonde. The orientation of
the four crossed-loop antennas is shown in Figure 8. All
eight receiving antennas were tested and the antenna cables
were equalized. An existing antenna switch was used to com-
bine the signals of the 12-antenna array into one input to
the new Antenna Switch.

```
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
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'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
'123456789BRRBDB'123456789BRRBDB'123456789BRRBDB
```

Figure 6.   Centronics Self Test

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Figure 7. Remote Printout with Centronics Line Printer
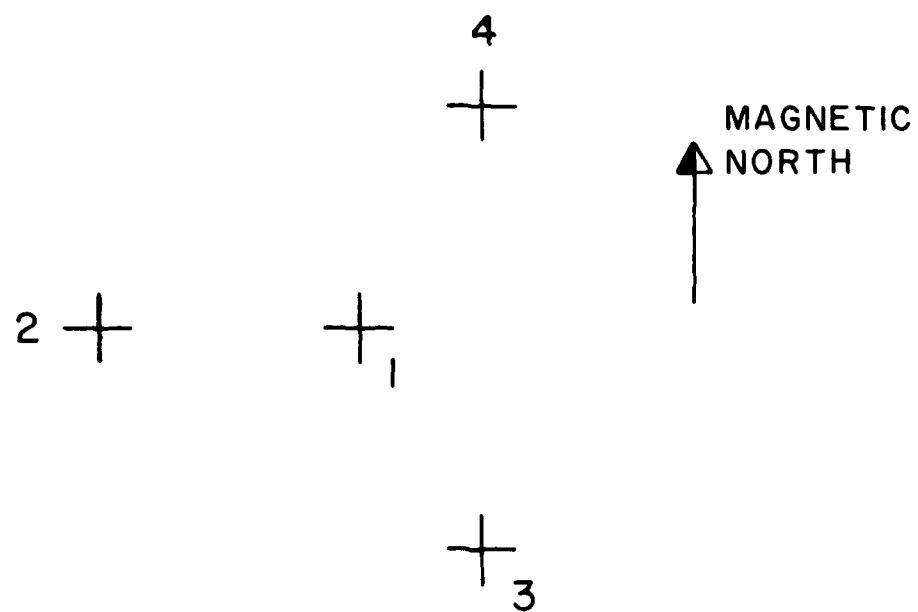
CROSSED LOOP ANTENNA SYSTEM
GOOSE BAY, LABRADOR

Figure 8

2.6 Iceland Sounder

The Digisonde 128 No. 3 was prepared for field operation at Keflavik NAS, Iceland, in support of the OTH radar tests. This Digisonde, originally operated in Maynard, Mass. and in storage at AFGL for six years, was in surprisingly good condition. The Memory, Synthesizer, and Translator sections of the "Iceland Sounder" were checked and repaired and the peripheral equipment, tape recorder and Magnafax printers, were tested. One printer was new and worked well, but the other needed a complete overhaul. The 30 kW Granger transmitter, which has not been operated during the last period of the sounder operation in Maynard, required a thorough check-out.

New designs for a pair of crossed rhombic antennas taking into account the site layout and pole locations at Keflavik were prepared. The Digisonde system and the antennas were installed at Keflavik in September 1979. Each rhombic antenna has a height of 97' (Figure 9) and the corners are 208' apart. The antenna conductor consists of three no. 14 gauge copperweld wires that are spread by 18' at the corners of the rhombic thus assuring a rather constant impedance over the frequency range from 1 to 16 MHz. An impedance measurement of the antennas was not performed. The managerial and technical on-site support by an AFGL engineer (Mr. Jack Waaramaa) greatly facilitated the timely execution of this task. Lectures and demonstrations were administered to the site operators explaining the system and the ionospheric data collected. A convenient calibration scheme for the Digisonde system was provided and the site personnel were instructed to run a calibration ionogram at the start of each new data tape.

2.7 Aircraft Digisonde 128PS

After each trip the Aircraft Digisonde 128PS chassis was returned to our laboratory for improvements and modifications. The analog part has been upgraded for a better signal

RHOMBIC CURTAIN
(3)#14 COPPERWELD WIRE

18 FOOT ALUM. TUBE

45'

44'

120'

112'

54'

208'

4'

100'

97'

208'

GND. LEVEL

ICELAND RHOMBIC ANTENNA

Figure 9

25
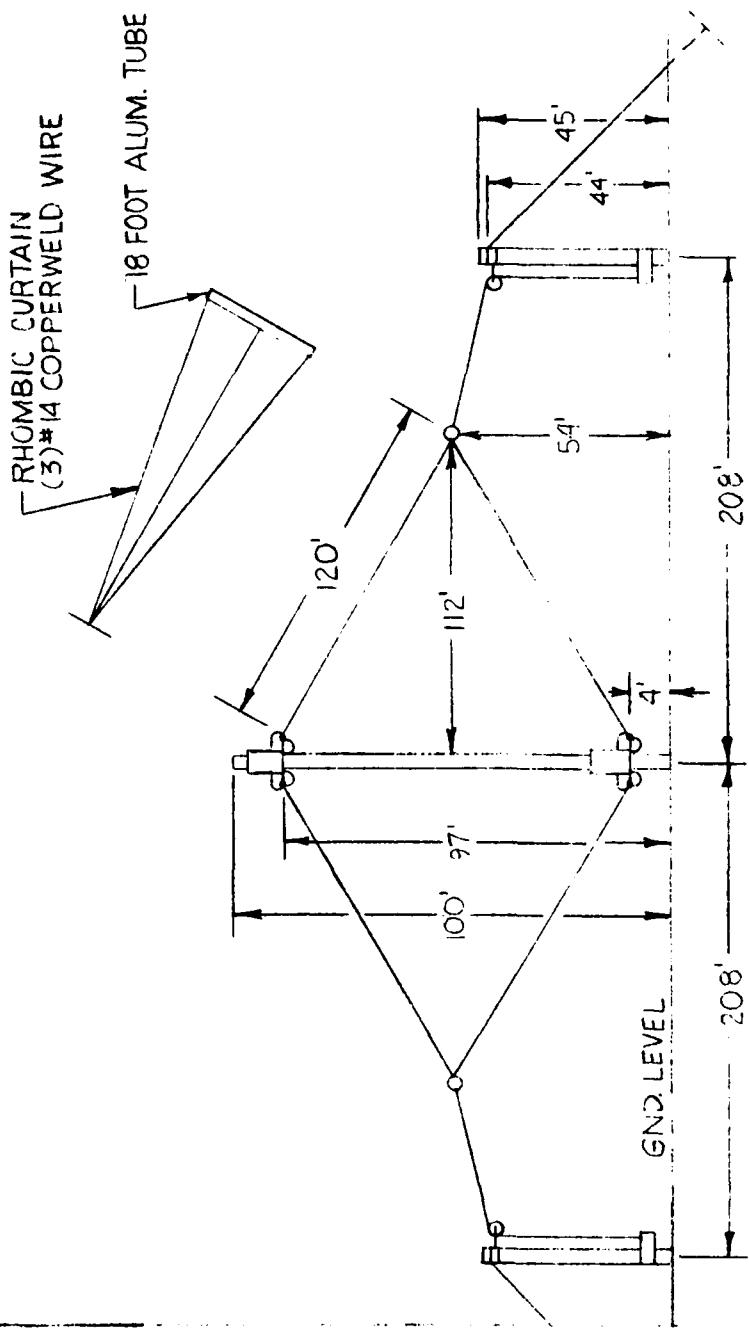
to noise ratio by narrowing the bandwidth after installation of the new 225 kHz Intermediate Frequency (IF) cards. Also the demodulated output for Oscilloscope display has been improved.

The digital chassis underwent several modifications to incorporate the improvements implemented in the two other systems (Goose Bay and Kwajalein, M.I.). Specifically, the equalization of the Doppler frequency sign in all operating frequency bands has been implemented to compensate for the complicated frequency synthesis in the original DGS 128 system. Intermittent faults, only visible in the very variable temperature environment of the aircraft, have been repaired.

To enable correct parameter selection during aircraft experiments, we prepared Table 5 which shows the Doppler frequencies as function of N (number of integrations) and R (repetition rate and spectral line spacing).

2.8   Field Trips

Several trips were made to Goose Bay. The October 1978 trip's main purpose was to reinstall the Digisonde 128PS after its repair following the lightning storms of July-August 1978. The November-December 1978 trip was in support of aircraft experiments. At that time the Geomonitor was repaired and drift measurements were made. The tape recorded drift data were technically not correct and could not be evaluated. Several modifications to the Versatec print output were made to increase the value of the status information. The extraordinary signals were suppressed in the on-line printout and in the data stream to the Geomonitor. Sequential ionogram examples with and without X-trace may be seen in Figure 10. It should be noted that all X-trace information is still retained on the ionogram tapes. In the hourly ionograms the X-traces were retained during the period from December 1978 to January 1979.

(N,R)				16 SELECTED SPECTRAL LINES*						
		4,0	.07	.2	.4	.6	.8	1.0	1.2	1.4
		4,1	.07	.2	.4	.8	1.4	2.0	2.7	3.5 (1.6)
	3,0	4,2	.13	.4	.8	1.2	1.6	2.0	2.3	2.7
	3,1	4,3	.13	.4	.8	1.6	2.7	3.9	5.5	7.0 (3.1)
2,0	3,2	4,4	.26	.8	1.6	2.3	3.1	3.9	4.7	5.5
2,1	3,3	4,5	.26	.8	1.6	3.1	5.5	7.8	10.9	14.1 (6.3)
1,0	2,2	3,4	.52	1.6	3.1	4.7	6.3	7.8	9.4	10.9
1,1	2,3	3,5	.52	1.6	3.1	6.3	10.9	15.6	21.9	28.2 (12.5)
1,2	2,4		1.04	3.1	6.3	9.4	12.5	15.6	18.8	21.9
1,3	2,5		1.04	3.1	6.3	12.5	21.9	31.2	43.8	56.3 (25.0)
1,4			2.08	6.3	12.5	18.8	25.0	31.2	37.5	43.8
1,5			2.08	6.3	12.5	25.0	37.5	50.0	62.5	75.0 (50.0)
0,0			1.04	3.1	6.3	9.4	12.5	15.6	18.8	21.9
0,1†			1.04	3.1	6.3	12.5	21.9	31.2	43.8	56.3
0,2			2.08	6.3	12.5	18.8	25.0	31.2	37.5	43.8
0,3†			2.08	6.3	12.5	25.0	37.5	50.0	62.5	75.0
0,4			4.17	12.5	25.0	37.5	50.0	62.5	75.0	87.5
0,5†			4.17	12.5	25.0	50.0	75.0	100.0	125.0	150.0

*Subsets of 8 and 4 are single or double under-lined; subset of two uses only first spectral lines.

†Highest Doppler frequencies of 16 spectral line set are redundant for single antenna modes.

Table 5. Spectral Width and Resolution for Single Antenna Spectral Integration in Ionogram Mode

Figure 10.   Digisonde 128PS X-Trace Suppression

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In November 1979 the digital automatic gain control was implemented. All antennas were tested to prepare for drift measurements. The frequency scans for the A, B and C programs (Section 2.) were extended to 18 MHz. During the night the end frequency is automatically reduced to 14 MHz.

The Aircraft Digisonde was modified to allow for external start commands of the A and B programs. Also, an external transmitter on/off switch is sensed and the off position is indicated in the preface of the recorded data by setting the 4-bit in the 100 digit of the day counter. A day count of 712, for example, means day 312 and transmitter off. This feature is helpful in the computer processing of the ionogram data.

In November 1979, the Geomonitor system was reinstalled in Goose Bay. In February 1980, a trip was made to Keflavik, Iceland, to reduce the interference which the Digisonde 128, installed there in September 1979, produced in other communication systems. The following modifications were made: (1) screen voltage of Granger transmitter was set to 2200V, (2) power of radiated signal was reduced by 11 dB over the entire frequency band, and additional 10 dB for the band 6 to 8 MHz, and 6 dB for 8 to 10 dB, (3) data integration was reduced from 320 to 160 samples without changing the frequency stepping time (2 sec). These modifications have diminished but not resolved the RFI problem.

In the same month the synchronization of the aircraft and Goose Bay Digisondes was completed by equalizing the timing of program start, signal integration and transfer time and the phase sequence code. Figure 11 shows an oblique ionogram received at the aircraft with Es, 1F and 2F propagacraft with Es, 1F and 2F propagation modes.
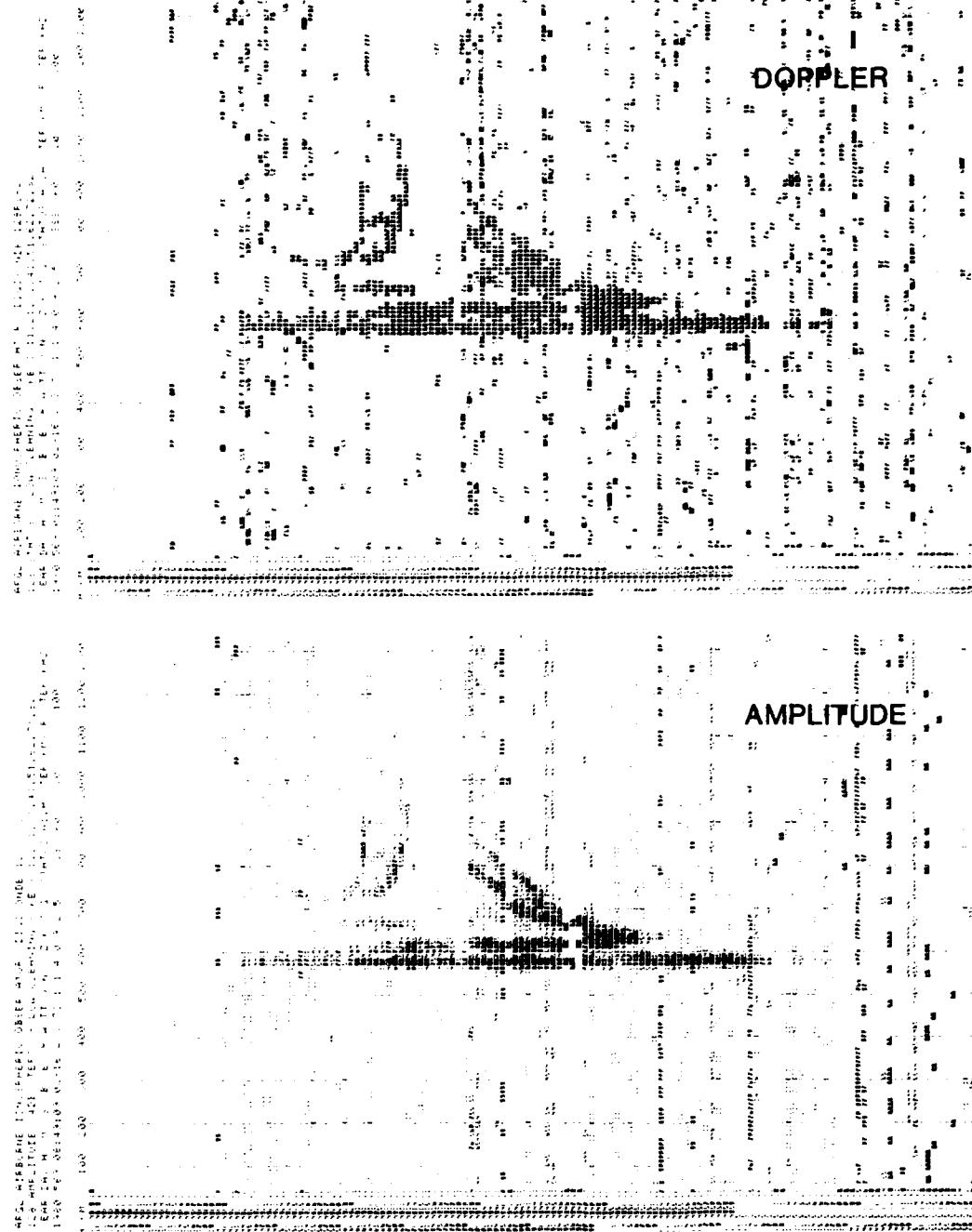
GOOSE BAY-AIRCRAFT OBLIQUE IONOGRAM

Figure 11

3.0 DATA PROCESSING

3.1 Fixed Frequency Program

A program was developed which extracts from each ionogram one specific frequency; provided the ionogram satisfies certain criteria, i.e. K = 7 (5 km/range bin). Since the total preface information (the K parameter specifically), is not available until the second record of the ionogram, it is advisable not to select any of the first ten frequencies in the ionogram. Data of the January 1979 aircraft expedition has been processed using this program. The example in Figure 12 shows the virtual height variation of the electron density surface $N_e = 10^{11}$ m^{-3}. This technique is more sensitive than the integrated-heights method, that we normally use, which sums the amplitudes at each height bin over all frequencies and applies a linear normalization. The equation for normalization is:

$$A_{i \text{ normalized}} = \frac{63}{(A_{max} - A_{min})} * (A_i - A_{min}).$$

The fixed-frequency program processes all ionograms with K = 7 at frequency f = 3.0 MHz in its default mode; a data card can be inserted in the program deck to vary frequency or type of ionogram to be processed. If several data cards are submitted the program will produce several N_e profiles.

A sample set of control cards to run this program is

1. SMITH,CM55000,T200,TP2.   3675 SMITHS

2. VSN,TAPE1=D79026.

3. REQUEST,TAPE1,HI,NR,S.(D79026/NORING).

4. VSN,TAPE7=F79026.
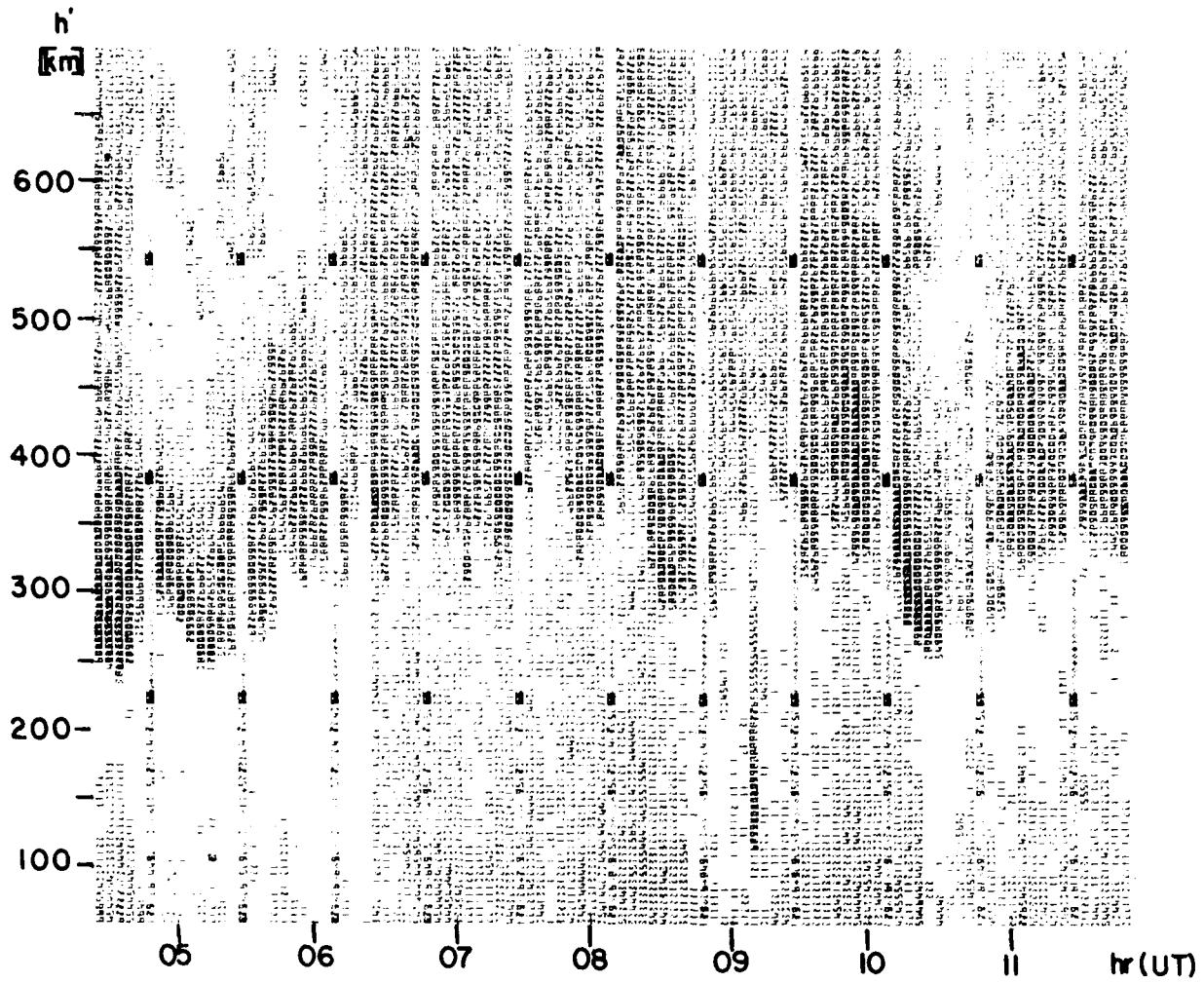
FIXED FREQUENCY
26 JANUARY 1979
LORING - THULE
0436 - 1149 [UT]

Figure 12

5. REQUEST,TAPE7,HI,RING,S.(F79026/RINGIN).

6. ATTACH,AAA,FXFRQ,ID=SMITHS,MR=1.

7. FTN,SL,I=AAA,R=3.

8. MAP,ON.

9. LGO.

10. EXIT.

11. 789

12. 3.0,17,0,21,7.

13. 789

14. 6789

3.2 Automatic Parameter Identification

A comprehensive program for automatic parameter
identification in digital ionograms was developed, which is
described in Scientific Report No. 1 (Smith et al, 1979).
The abstract of this report is reproduced here.

AUTOMATIC IONOSPHERIC PARAMETER EXTRACTION FROM DIGITAL IONOGRAM DATA

"Development of techniques to automatically extract
the ionospheric ionization parameters of foF2, M(3000), fmin,
and ftEs from digital ionograms have become feasible with the
advent of advanced digital sounders. From digital ionogram
data of the Digisonde 128PS the six most significant echoes
for each frequency are extracted in the Geomonitor. They are
further processed in the Automatic Parameter Evaluation pro-
gram (A.P.E.) to determine the main echo height for each fre-
quency. The program takes into consideration the frequency
continuity of the reflection height, multiple hop reflection
heights, rate of change of slope and the physical properties
of the ionogram such as foE's dependence on the solar zenith
angle. The output data are mathematically smoothed to produce

a refined ionogram. From this refined ionogram the A.P.E. program determines the four ionospheric parameters. In a study of 1500 ionograms the automatically evaluated ionogram parameters are compared with the manually scaled values and the differences are analyzed statistically. Also some case studies are discussed concentrating on the reasons for larger deviations. The program has been written considering the future possibility of implementation in a microcomputer which can integrate the functions of the Geomonitor, as well as a True Height Analysis program."

3.3 Playback of Aircraft Ionograms with Microcomputer

Aircraft ionograms from day 079-080, 1979 have been played back from magnetic tape to display amplitude and status (Figure 13) using ULCAR's Microcomputer chassis which forms part of a standard Digisonde 128PS. The software of the Microcomputer was revised to display the echoes with positive and negative Doppler in separate ionograms (Figure 14). Originally the status words have different meanings for different ionogram modes varying with Tt, R and N. This makes it difficult to compare different mode ionograms in terms of signal Dopplers. By encoding the status word as a function of Tt, R and N, the Doppler values in the ionogram are now printed independent of the ionogram mode using the Doppler-Group-Numbers (Table 6).

3.3.1 Amplitude-Status Ionograms

The actual set-up for the Microcomputer to run amplitude-status ionograms is:

1) Load tape without write ring on synchronous tape recorder.

2) Make sure KJ tape recorder cable and KP printer (Versatec) cables connect Microcomputer to peripherals.

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STATUS

AMPLITUDE AND
STATUS IONOGRAMS
AIRCRAFT
26 JAN 1979

AMPLITUDE

0534 (UT)

0529 (UT)

Figure 13

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NEGATIVE DOPPLER

DOPPLER-SPLIT
IONOGRAMS
AIRCRAFT
26 JAN 1979

POSITIVE DOPPLER

0534 (UT)

0529 (UT)

Figure 14

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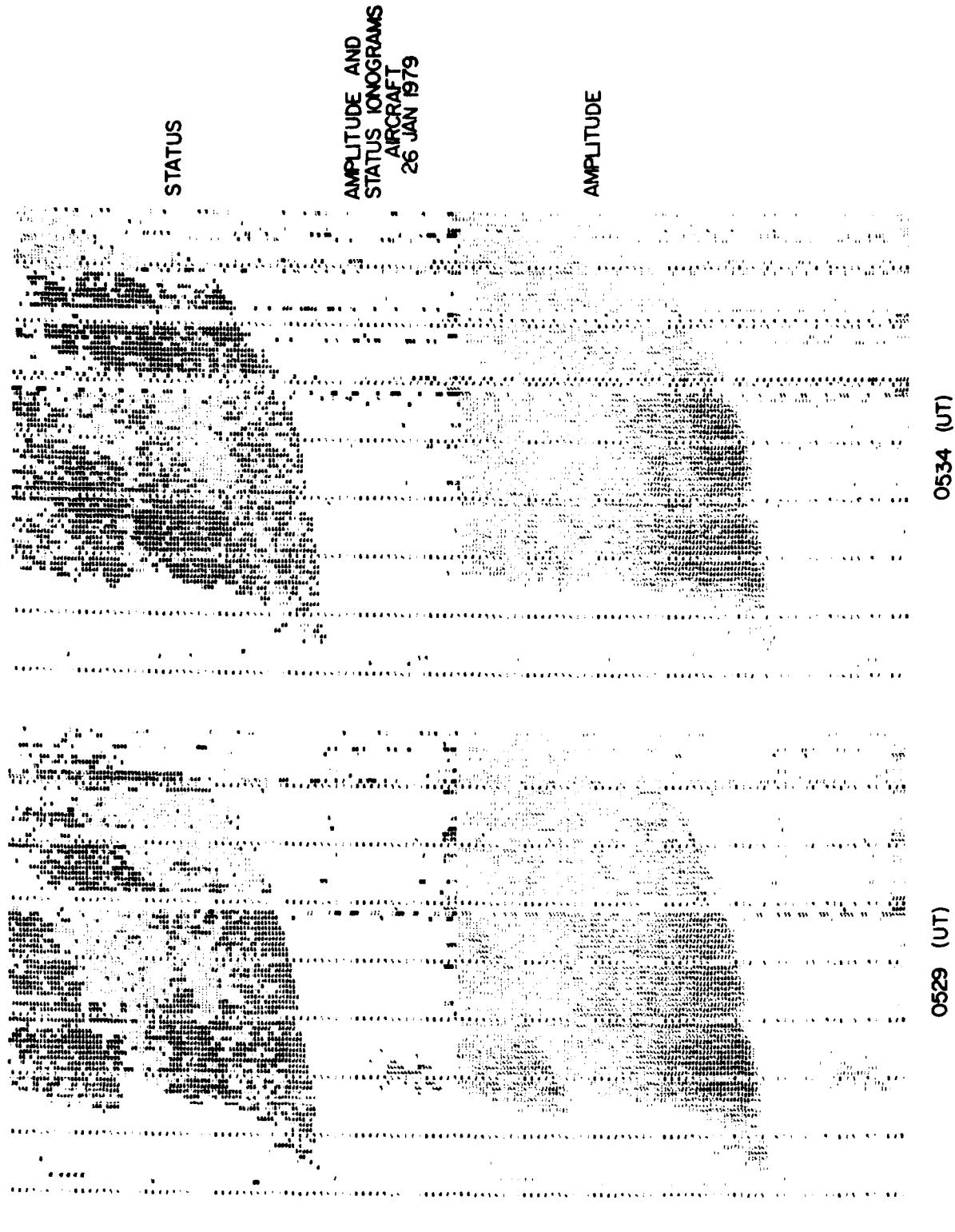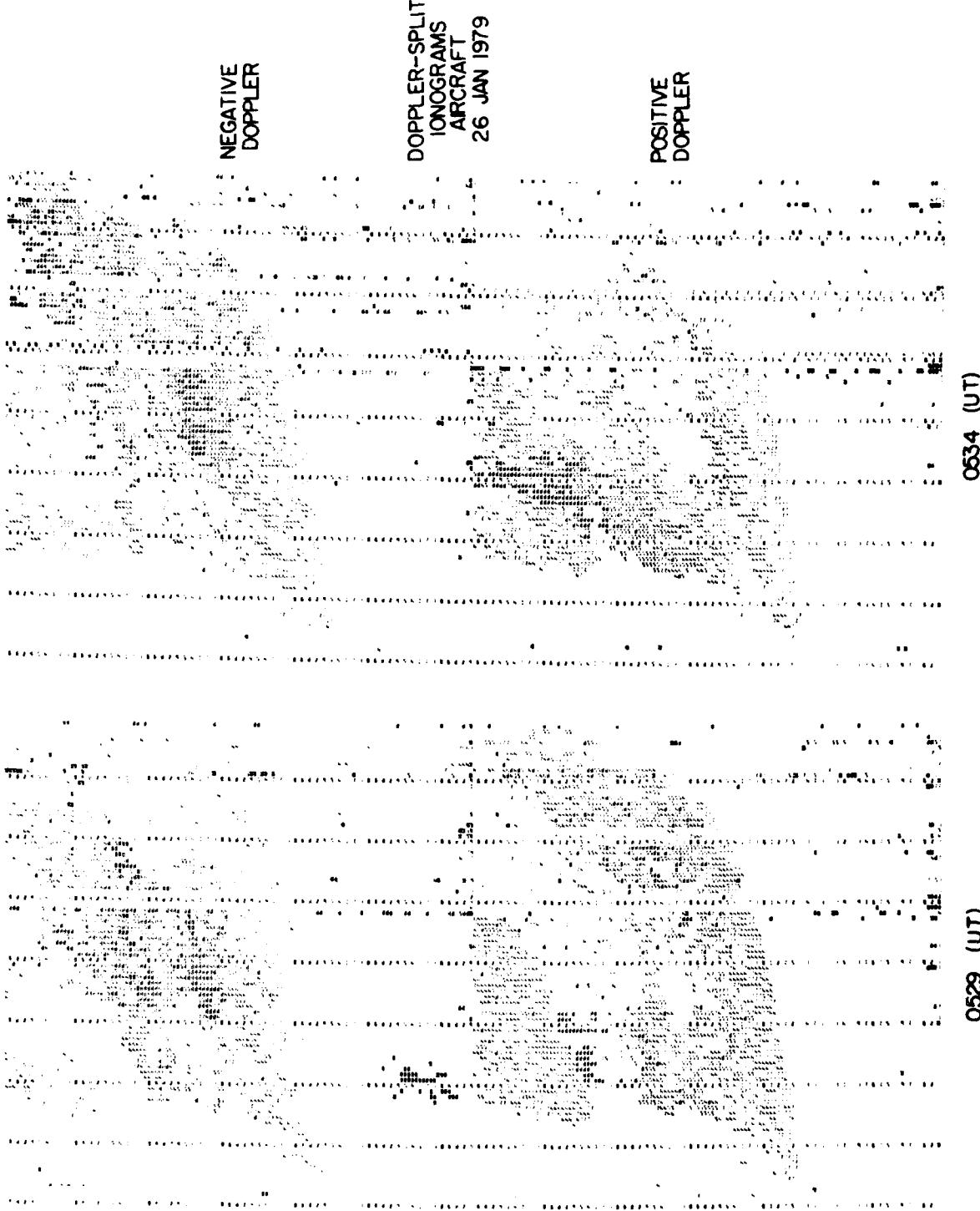
In the program for Doppler-Split Ionograms the displayed numbers represent the magnitudes of the Doppler frequencies in a non-linear scale.

No. Represented	Doppler [Hz]
1	$0 < S < .52$
2	$.6 < S < 1.4$
3	$1.6 < S < 2.3$
4	$2.7 < S < 4.7$
5	$5.5 < S < 6.3$
6	$7.0 < S < 7.8$
7	$9.4 < S < 10.9$
8	$12.5 < S < 14.1$
9	$15.6 < S < 18.8$
10	$S = 21.9$
11	$S = 25.0$
12	$28.2 < S < 31.2$
13	$37.4 < S < 43.8$
14	$50.0 < S < 56.3$
15	$62.5 < S < \infty$

Table 6. Scale of Doppler Group Number for Doppler-Split Ionograms

3) Command Microcomputer

ME000 F7FF 4000 (RET)

This loads working program from PROM into RAM.

4) Depress front panel buttons [1] and [MODE]. This de-
fines a AKADN (read from tape) operation.

5) Turn printer ON.

6) Command Microcomputer

G4198 (RET)

Versatec will execute a form feed.

7) Depress ON-LINE on tape recorder. Tape will advance and
the Versatec will begin printing. After ten lines are
printed, the tape will advance reading the next record.

8) Remove button [1]. This will process data with noise
cleaning. The lowest four height bins will show the raw
data and the height bins 5-128 will have all data with
echoes less than or equal to NOISE set equal to zero.
The noise threshold is simply defined as the amplitude
average over the first four range bins:

$$NOISE = \frac{\sum_{i=1}^{4} M(i)}{4} + 5$$

where M(i) = 6 bit magnitude. If the LSB of the magni-
tude contains status information the error is ±1 dB.

With button [1] depressed no cleaning is performed
on the data. For the aircraft this is usually unacceptable.

3.3.2 "Split-Doppler" Ionogram

To run "Split-Doppler" ionograms:

1) Repeat steps 1 - 3 from Section 3.3.1.

2)   Command Microcomputer

```
·  S4617 FE 1B
   S4660 C5 01 00 6A C3 7A 46
   S463A C5 01 10 6A C3 7A 46
   S4594 CD A8 45
   S45DF C3 F4 45
   S45F5 C6 08 E6 OF 00 00 00 00
   S4659 00 00 00
   S4624 C3 40 6A
   S6A40 21 00 3E 11 80 3D 06 80
         CD 9F 45 C1 D1 E1 C9
   S42CD 00 00 00
   S4680 7B FE 10
   S464E E6 OF
```

3)   Command Microcomputer

```
   S45BA C3 01 46
```

4)   An equivalence table for each ionogram mode must be
      placed in RAM. The RAM space allocations for the Doppler
      Group Number (DGN) are as follows:

```
      Tt = 73    4689 - 4698
      Tt = 63    6A00 - 6A0F
      Tt = 60    6A10 - 6A1F
```

For example, for program Tt = 63 N = 1, R = 3, the
equivalent table is:

STATUS	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
DGN	02	05	08	0B	02	05	08	0B	12	15	18	1B	12	15	18	1B

In the equivalence table the sixteen bit, 10H, indicates
the sign of the Doppler. For any new ionogram mode the
equivalence table must be determined by using 8, 5 and 7
and placed in RAM for the "Split-Doppler" presentation.
As it stands now, for each Tt only one N, R combination
is allowed, but this limitation can be overcome by ex-
panding the program.

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3.3.3 Doppler Sign Inversion

Prior to December 1978 the sign of the Doppler produced by the Digisonde changed from frequency band to band due to the method of frequency synthesis. The Microcomputer has the relevant firmware to correct for the sign switching. Following steps must be done to run the program:

Amplitude-Status Display with Doppler Sign Inversion:

1)   Repeat steps 1 - 3 of Section 3.3.1.

2)   Command Microcomputer

      S4601 C3 24 46
      S4594 CD A8 45

3)   Repeat steps 4 - 8 of Section 3.3.1.

Split-Doppler Presentation with Sign Correction:

1)   Repeat steps 1 - 2 of Section 3.3.2.

2)   Exclude instruction 3.

3)   Repeat step 4 of Section 3.3.2.

3.4 Special Programming

Several new programs were developed for the processing of digital ionogram data based on the existing Automatic Iono-gram Reduction (AIR) program (Bibl et al, 1976).

3.4.1 Adapting AIR to the Digisonde 128PS

The AIR program had been tailored toward DGS 128 ionograms. Since both at Goose Bay and in the Aircraft the new 128PS systems are in operation, the program was modified to take account of the new preface structure. This program version, dubbed AIRPS, was tested and is in operational condition.

3.4.2 Expansion of the AIRPS Program

A new output tape of the AIRPS program is generated as an input for an AFGL data mapping program. This new "MAIRPS tape" contains the amplitudes of one echo each for E and F region, respectively, for each of 170 frequencies per ionogram, always starting at 1.0 MHz. Appended to these data is the integrated height array.

A fixed frequency routine was added to the AIRPS program. For three selectable frequencies the heights of the main E and F echo are extracted and outputted on the MAIRPS tape. If no selection is made 3.5, 4.5 and 5.5 MHz are taken by default.

The data are preceded by a Doppler indicator, as explained in the next paragraph, and a 33 word preface, where the first two preface words contain the station identifier, i.e. 2 - 12 for the Aircraft Digisonde. The tape is written in CDC computer words each record containing 556 words as shown in Table 7.

The MAIRPS program also classifies all data according to their sign of the Doppler shift. As a result each MAIRPS output tape has three files. The first file contains the MAIRPS data obtained from processing the ionograms without regard to the Doppler frequency. This is indicated by a zero in the leading word in each record. The second file is the result of processing only the ionogram data with positive Doppler, indicated by a +1 as leading word. The third file, marked by a -1 as leading character in each record, contains the negative Doppler signals.

Word No.	Explanation
1	Doppler Identifier (0, 1 or -1)
2 - 34	Preface
35 - 204	170 F Amplitudes
205 - 374	170 E Amplitudes
375 - 544	128 Integrated Heights + 42 Zeroes
545 - 550	FQ1, HF(FQ1), FQ2, HF(FQ2), FQ3, HF(FQ3) (Fixed Frequency)
551 - 556	FQ1, HE(FQ1), FQ2, HE(FQ2), FQ3, HE(FQ3) (Fixed Frequency)

Table 7. Record Format on MAIRPS Tape

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4.0   DATA ANALYSIS

4.1   Routine Ionogram Scaling

Two years of Goose Bay ionograms, 1977 and 1978,
were scaled in terms of the following parameters: foF2, foF1,
h'F, MUF3000, foE, h'E, foEs, fbEs, h'Es, fmin. For oblique
echoes on the "vertical" ionograms the following parameters
were scaled: ftEs, h'Es, ftF and h'F. Punch cards were pre-
pared in accordance with URSI specifications, but extended to
include the oblique parameters. Table 8 explains the format.
The monthly median curves for the period January 1977 to
December 1978 for foF2, foF1, foE, h'F2, h'F1, h'E, h'Es and
the foEs distribution functions are shown in Appendix A of
this report.

Some analysis of aircraft ionograms was performed
and results were supplied to AFGL.

4.2   Ionogram Scaling Seminar

In September 1979 ULCAR conducted a special course
on the scaling of digital ionograms with emphasis on the Goose
Bay ionograms. This course, conducted by Miss Sheryl Smith,
was given to personnel of the Air Weather Service, responsible
for the ionogram interpretation at the OTH Radar Site in Maine,
to the operators and data technicians of Marconi Canada, in
charge of the Goose Bay Ionospheric Observatory, and to new
personnel of ULCAR.

Table 8. Punch Card Format for Ionogram Parameters

Height Card #1		Frequency Card #2		Supplement Card #3	
		Freq. in 20 kHz			
Heights in km		MUF in 100 kHz			
1-2	Card Code	1-2	Card Code	1-2	Card Code
3-5	Station	3-5	Station	3-5	Station
6-7	Year	6-7	Year	6-7	Year
8-9	Month 01-12	8-9	Month 01-12	8-9	Month 01-12
10-11	Day 01-31	10-11	Day 01-31	10-11	Day 01-31
12-13	Hour 00-23	12-13	Hour 00-23	12-13	Hour 00-23
14	ƀ	14	ƀ	14	ƀ
15-17	h'E	15-17	fmin	15-17	h'Es
18-19	Q+D	18-19	Q+D	18-19	Q+D
20	ƀ	20	ƀ	20	ƀ
21-23	h'Es	21-23	foE	21-23	h'Fob
24-25	Q+D	24-25	Q+D	24-25	Q+D
26	ƀ	26	ƀ	26	ƀ
27-29	h'F	27-29	frEs	27-30	ƀ
30-31	Q+D	30-31	Q+D	31	Type Es2
32	ƀ	32	ƀ	32	ƀ
33-35	h'F2	33-35	fbEs	33-35	fminFob
36-37	Q+D	36-37	Q+D	36-37	Q+D
38	ƀ	38	ƀ	38	ƀ
39-41	hpF2	39-41	foEs	39-41	foEs2
42-43	Q+D	42-43	Q+D	42-43	Q+D
44	ƀ	44	ƀ	44	ƀ
45	Type Es	45-47	foI	45-47	foFob
46-80	ƀ	48-49	Q+D	48-49	Q+D
		50	ƀ	50-80	ƀ
		51-53	foF1		
		54-55	Q+D		
		56	ƀ		
		57-59	foF2		
		60-61	Q+D		
		62	ƀ		
		63-65	foT		
		66-67	Q+D		
		68	ƀ		
		69-71	MUFF1		
		72-73	Q+D		
		74	ƀ		
		75-77	MUFF2		
		78-79	Q+D		
		80	ƀ		

NOTE: All fields beyond column 14 may be replaced by Descrip-
tive letter (D) only. All fields may be blank (ƀ)
except: Cards 1-2-3 columns 1-13; Card 1 columns 27-
31, 39-43, and 15-19 during daytime; Card 2 columns
15-19, 57-61, 75-79, and 21-25 during daytime.

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5.0 PUBLICATIONS

A number of publications and reports used results of the research and development performed under this project. All papers give proper credit to the Air Force support received.

1. K. Bibl and B. W. Reinisch, "The Universal Digital Iono-sonde," 1978, Radio Science, 13, 519-530.

2. K. Bibl and B. W. Reinisch, Digisonde 128PS - System Description and Manual," 1978.

3. S. Smith, B. W. Reinisch, D. F. Kitrosser and K. Bibl, "Remote Ionogram Communicator - ICOM," 1979, University of Lowell Center for Atmospheric Research.

4. S. Smith, B. W. Reinisch, J. S. Tang and K. Bibl, "Auto-matic Ionospheric Parameter Extraction from Digital Iono-gram Data," 1979, AFGL-TR-80-0102, Scientific Report No. 1.

5. K. Bibl, "Complex Amplitudes of Spectrum Analyzed Iono-grams," 1978-1979, Rivista Italiana di Geofisica e Scienze Affini, Vol. V, pp. 111-114.

6. K. Bibl and B. W. Reinisch, "Digital On-Line Processing and Display of Multiparameter HF Transmission Data," AGARD, Lisbon Conference Proceedings No. 263, pp. 46-1 to 46-9.

Presentations were made at the XIX International URSI Meeting in Helsinki, Finland (1978), at the IUGG General Assembly in Australia (1979) and at the North American URSI Meeting in Quebec, Canada (1980).

6.0 PERSONNEL

The work reported here could not have been success-ful without the dedicated support by the following members of ULCAR:

Mr. Richard B. Bemis
Mr. James F. Gorman
Miss Selma E. Johnson
Mr. William T. Kersey
Mr. David F. Kitrosser
Mrs. Claire T. LeClair
Miss Sheryl Smith
Miss Jane S. Tang

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"Remote Ionogram Communicator - ICOM," University of Lowell
Center for Atmospheric Research.

APPENDIX A

MONTHLY MEDIAN VALUES FOR 1977 AND 1978

JANUARY, 1977
GOOSE BAY, LABRADOR
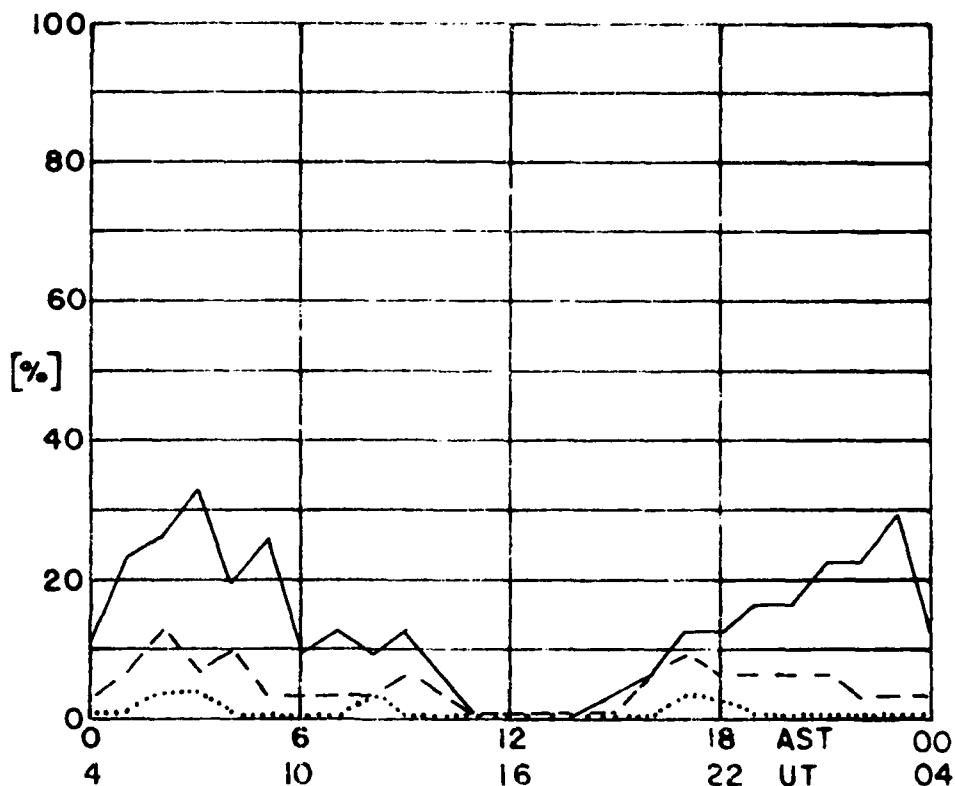
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — —— — —— —

LIMITING FREQUENCY = 7MHz · · · · · · · ·   · · · · ·

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR JANUARY, 1977
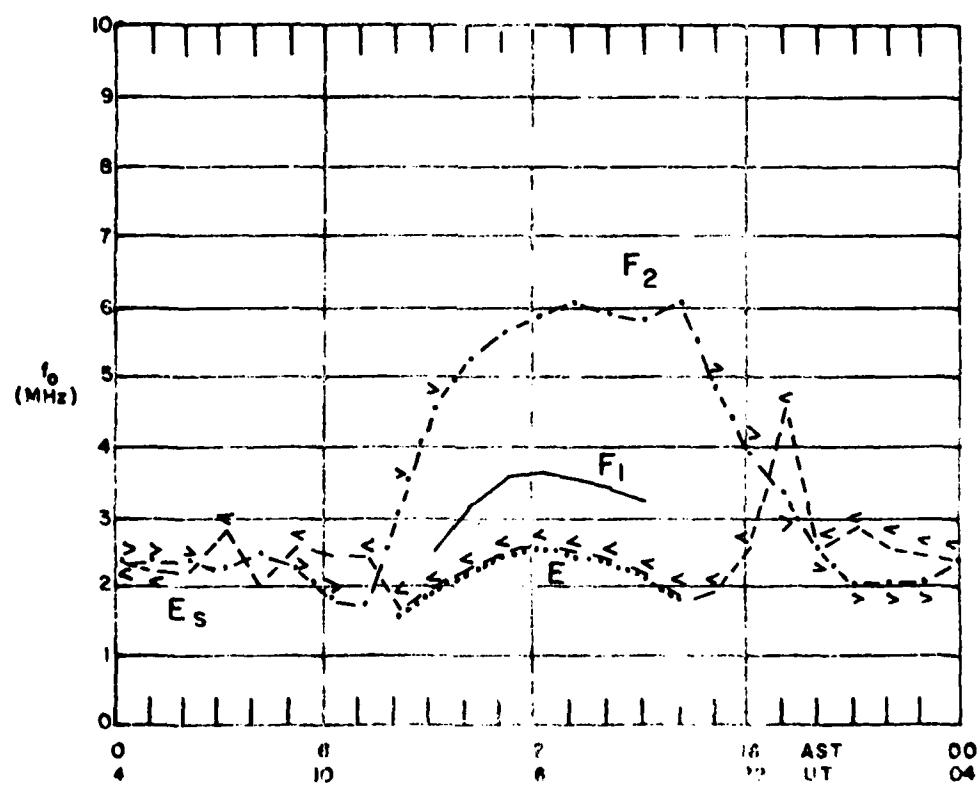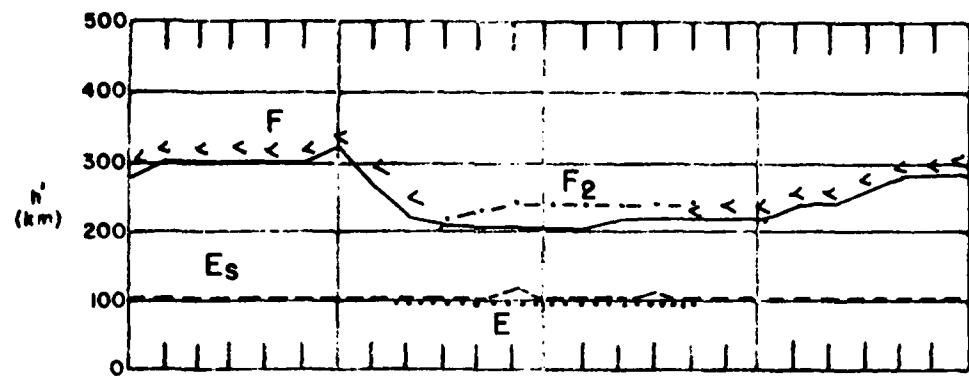
# FEBRUARY, 1977
GOOSE BAY, LABRADOR
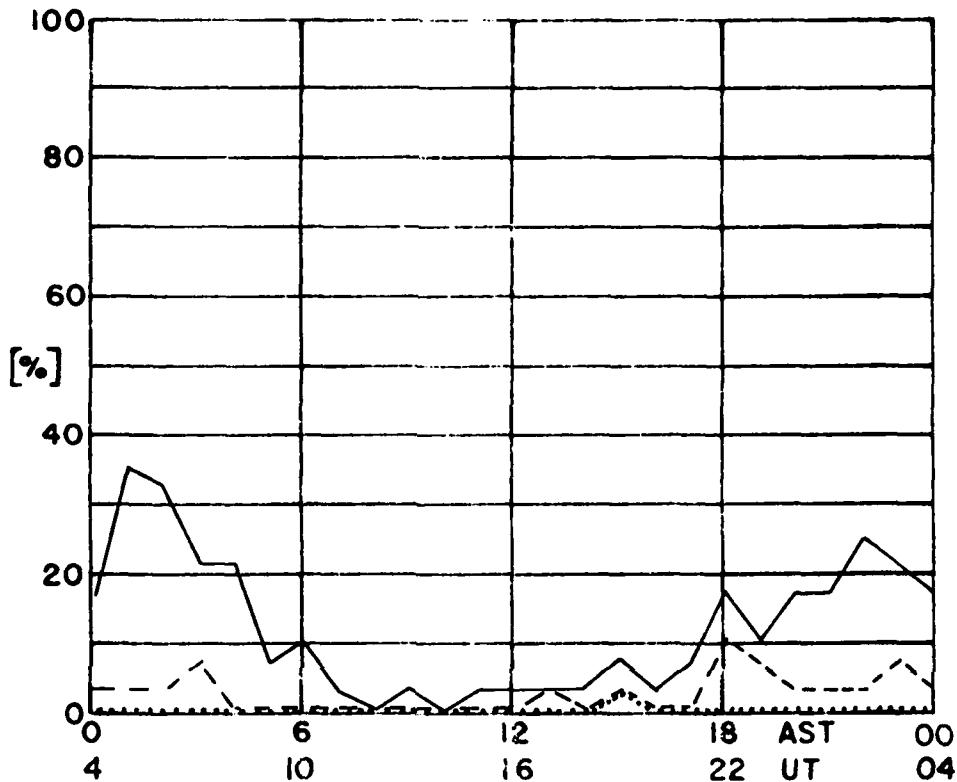
LIMITING FREQUENCY = 3MHz ─── ──

LIMITING FREQUENCY = 5MHz ── ·· ·· ──

LIMITING FREQUENCY = 7MHz ············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h'AND f_o AT GOOSEBAY, LABRADOR FOR **FEBRUARY, 1977**

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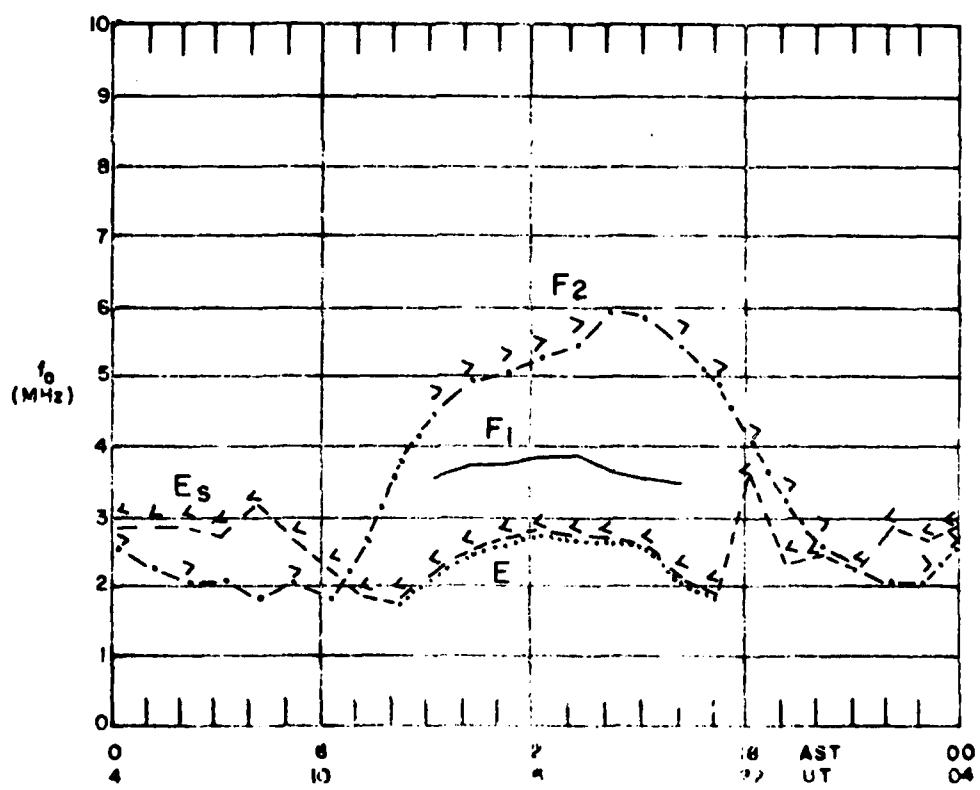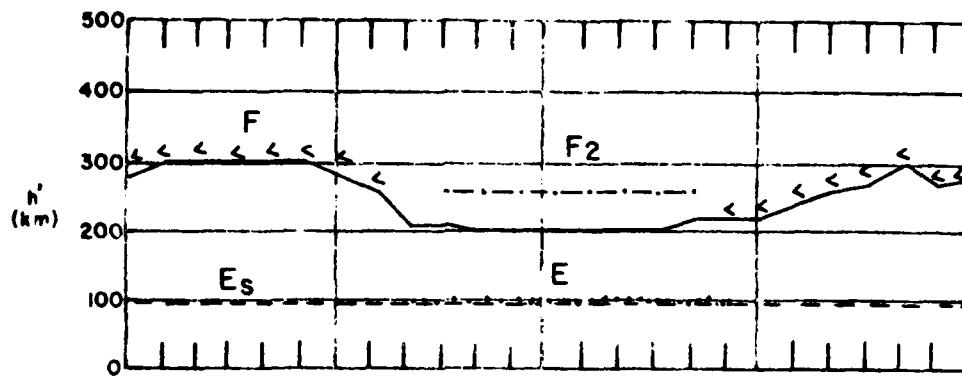
MARCH, 1977
GOOSE BAY, LABRADOR
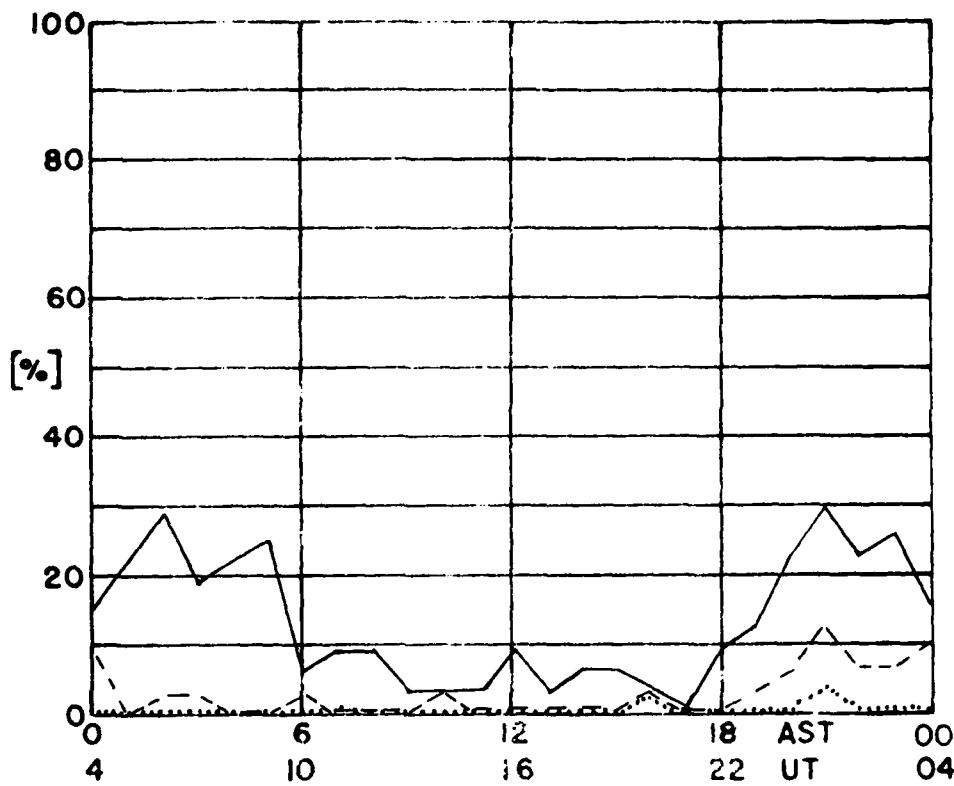
LIMITING FREQUENCY = 3MHz ——————
LIMITING FREQUENCY = 5MHz — —— — —
LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR MARCH, 1977

55
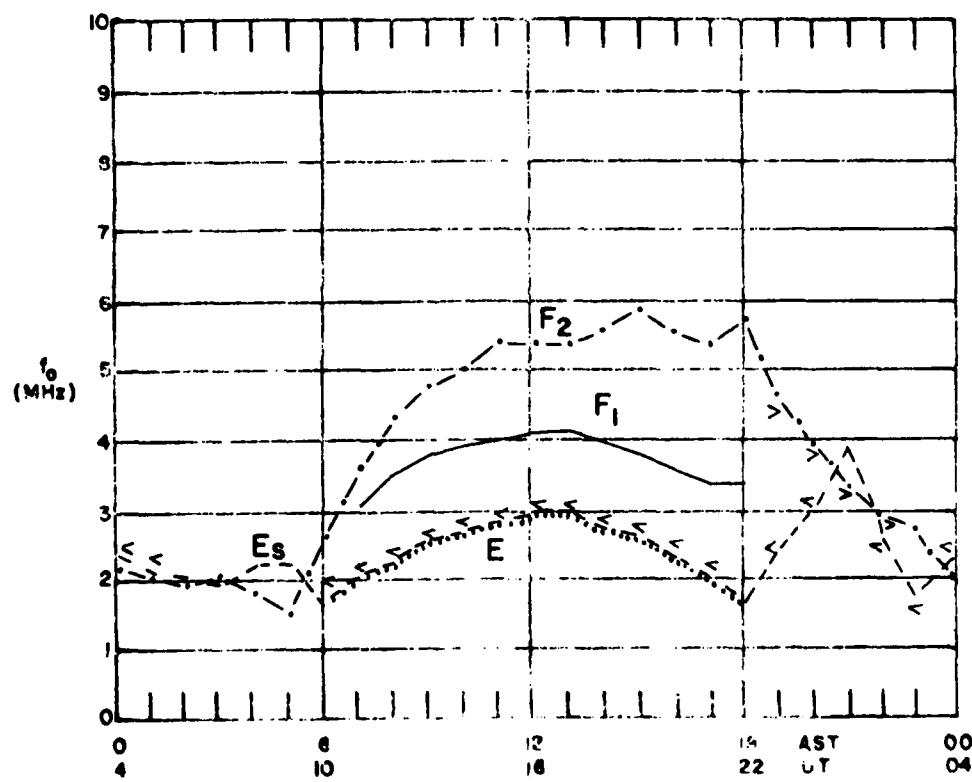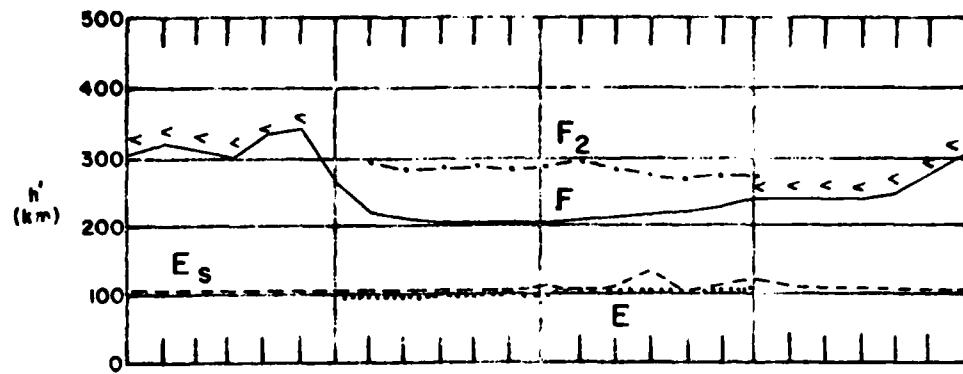
APRIL, 1977
GOOSE BAY, LABRADOR
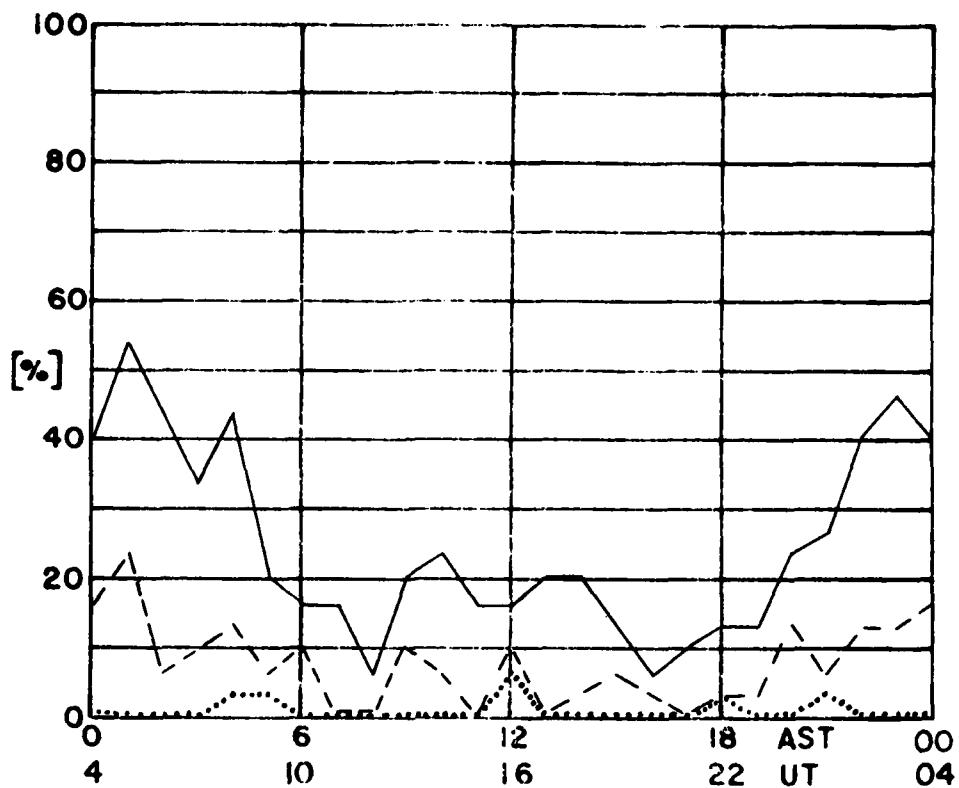
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — — —

LIMITING FREQUENCY = 7MHz · · · · · · · · · · · · · · ·

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f₀ AT GOOSE BAY, LABRADOR FOR APRIL, 1977

57
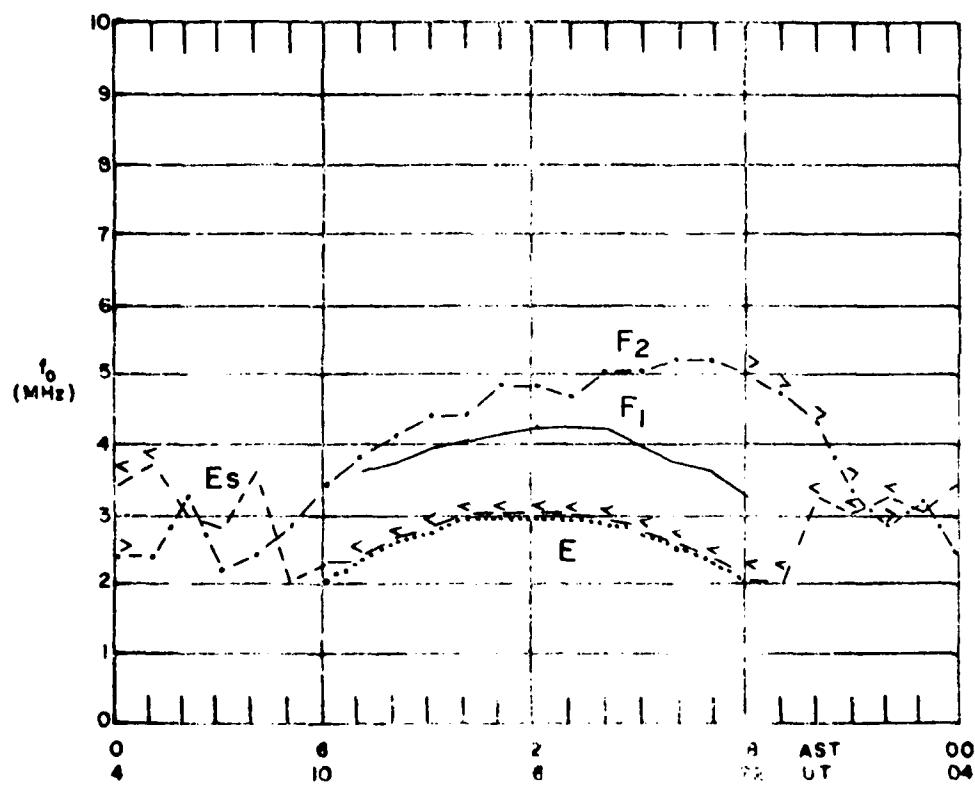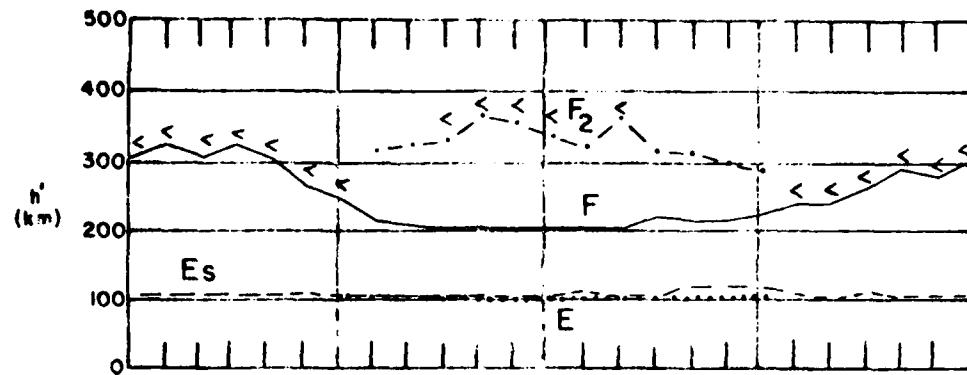
MAY, 1977
GOOSE BAY, LABRADOR
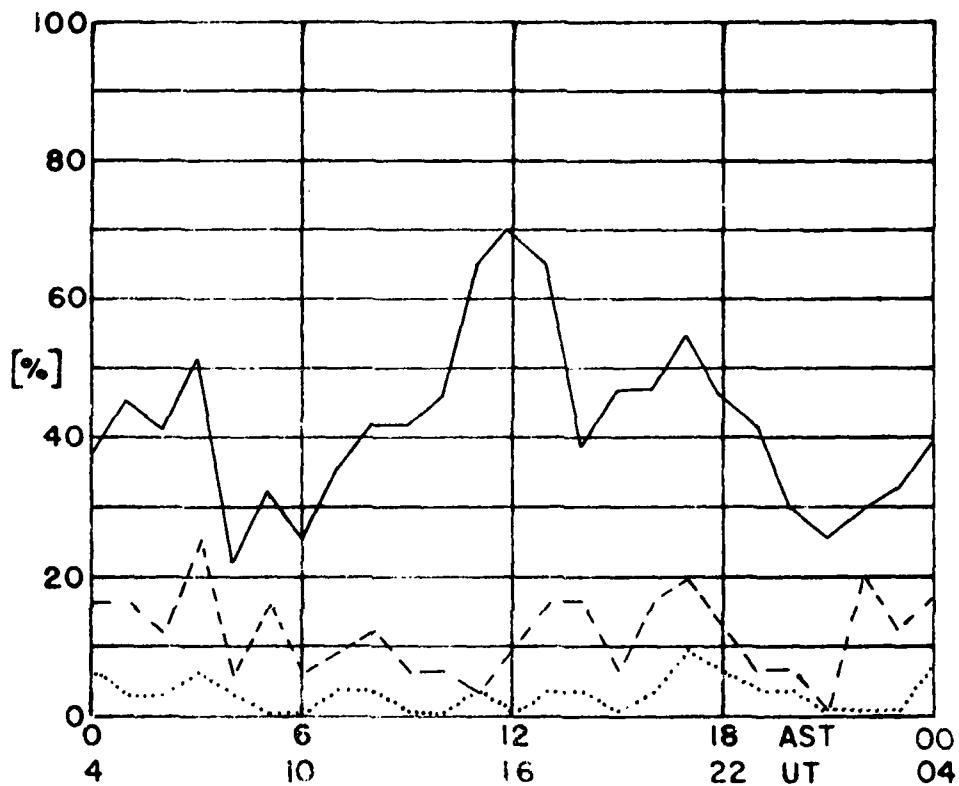
LIMITING FREQUENCY = 3MHz ————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f$_0$ AT GOOSEBAY, LABRADOR FOR MAY, 1977
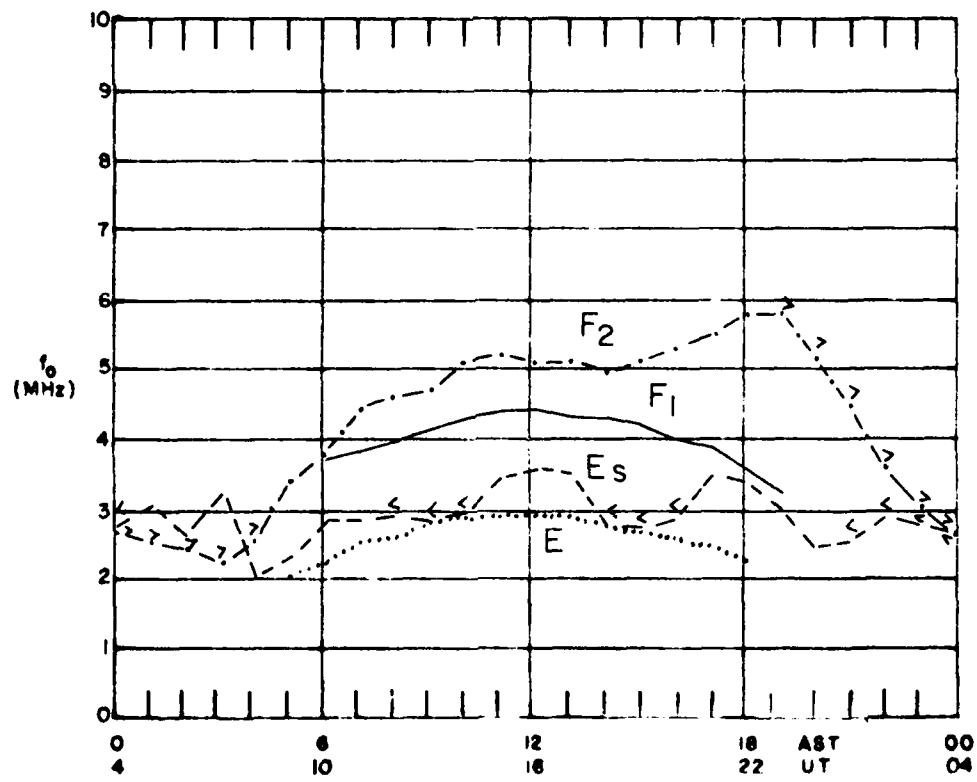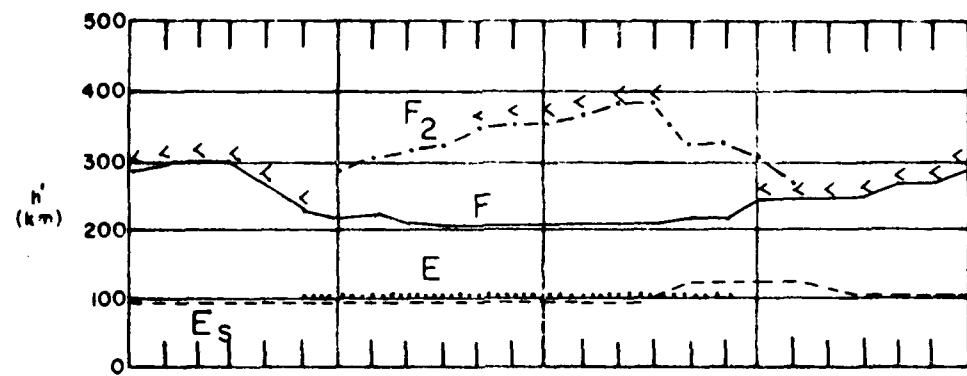
JUNE, 1977
GOOSE BAY, LABRADOR
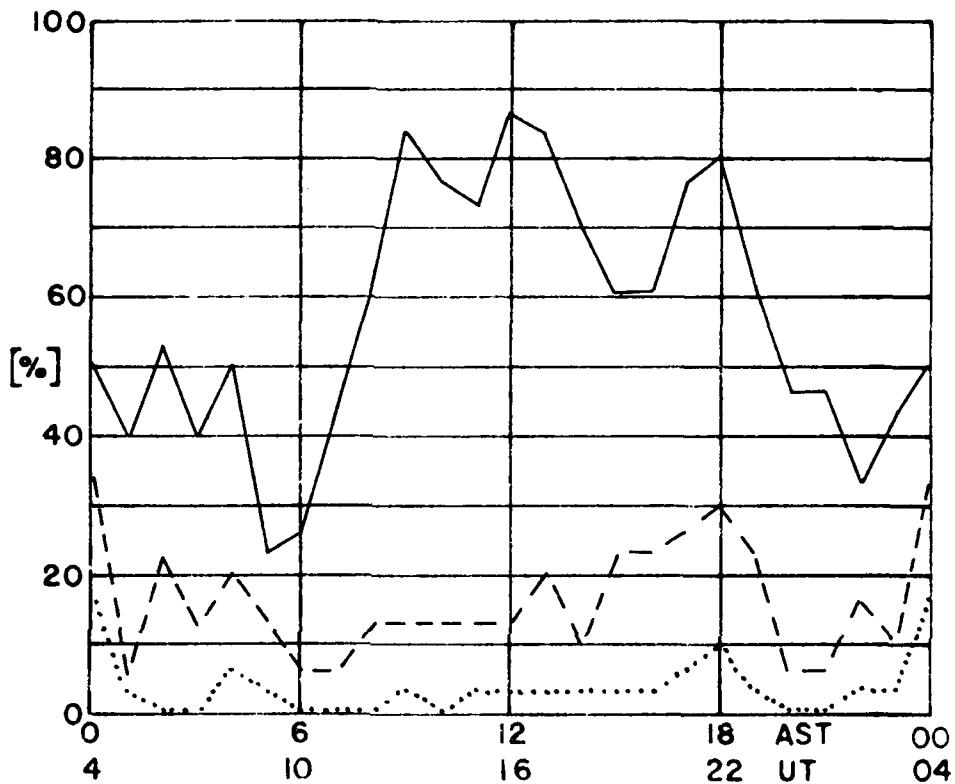
LIMITING FREQUENCY = 3MHz   ———————

LIMITING FREQUENCY = 5MHz   — — — — —

LIMITING FREQUENCY = 7MHz   · · · · · · · · · · · ·

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

60

MEDIAN VALUES OF h'AND f₀ AT GOOSEBAY, LABRADOR FOR JUNE , 1977

61
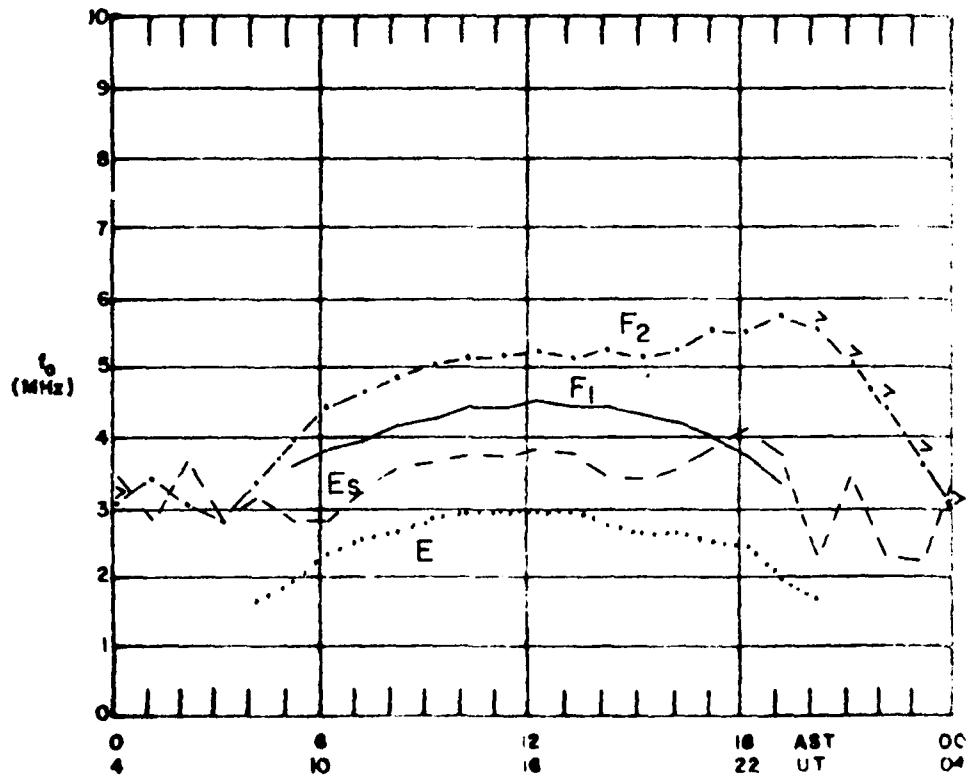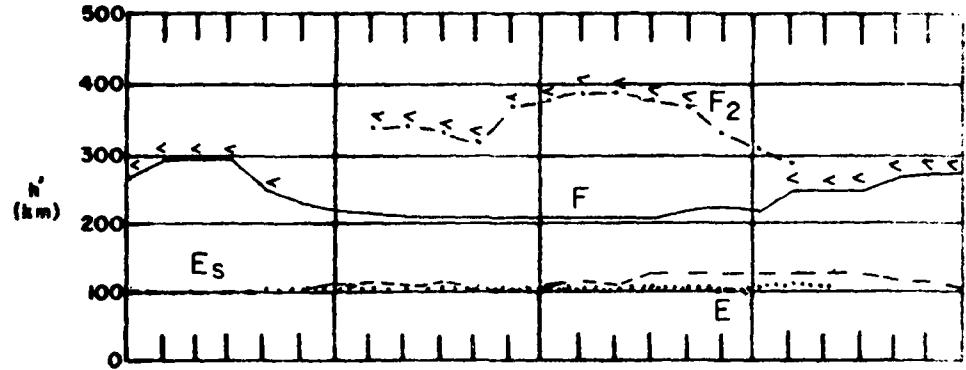
JULY, 1977
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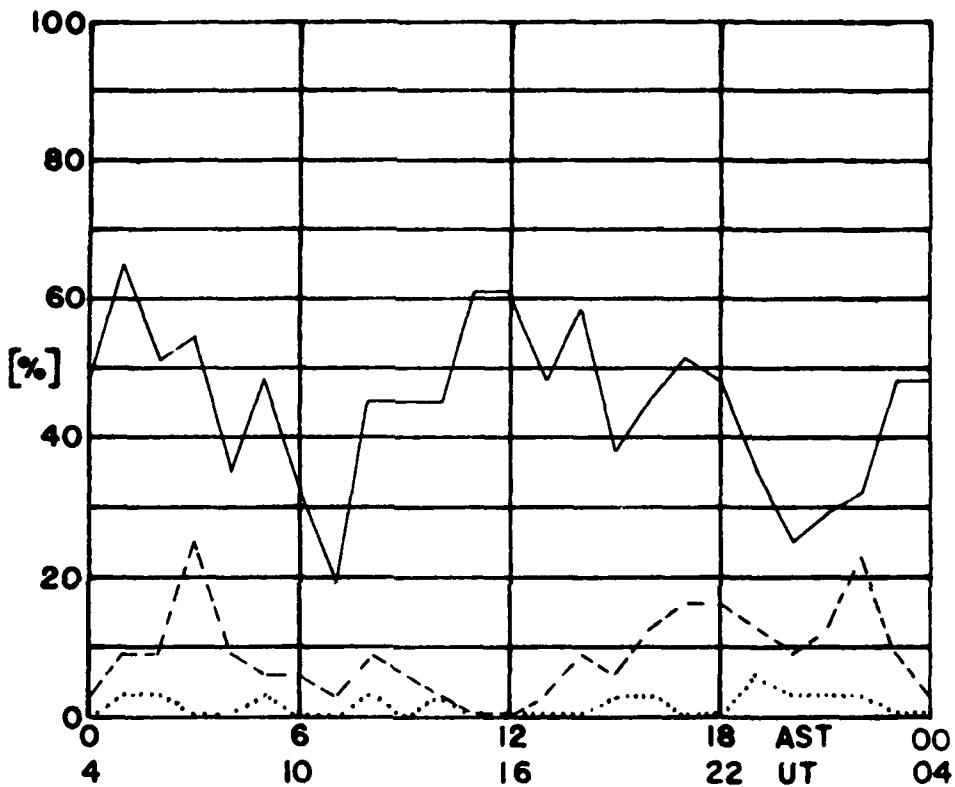
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

62

MEDIAN VALUES OF h' AND f_0 AT GOOSEBAY, LABRADOR FOR JULY, 1977
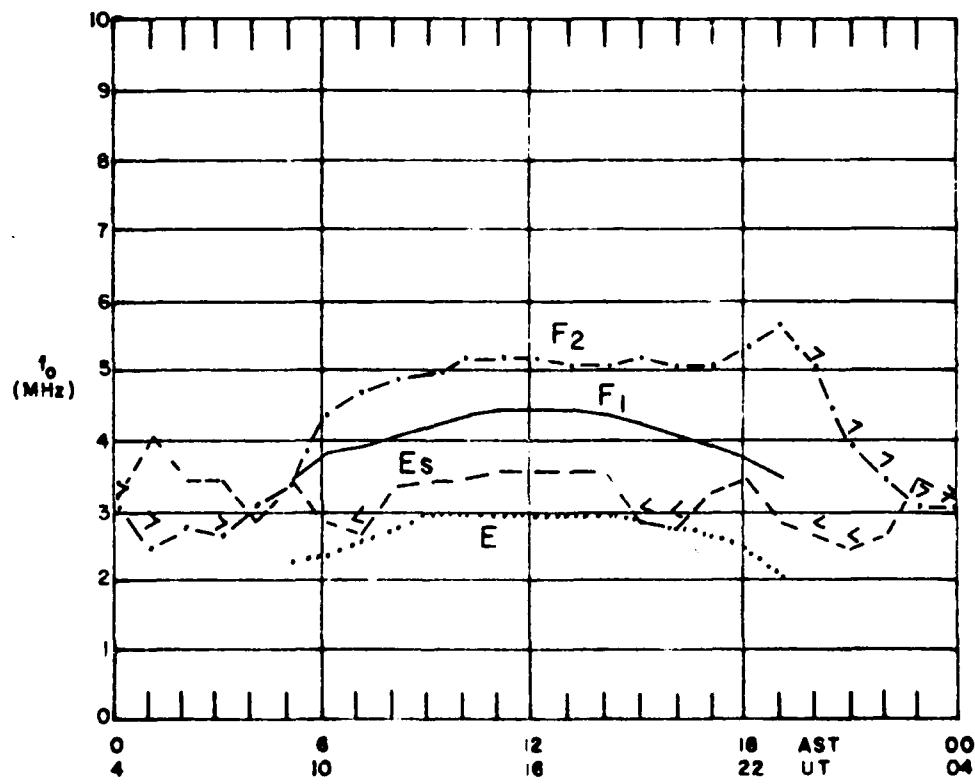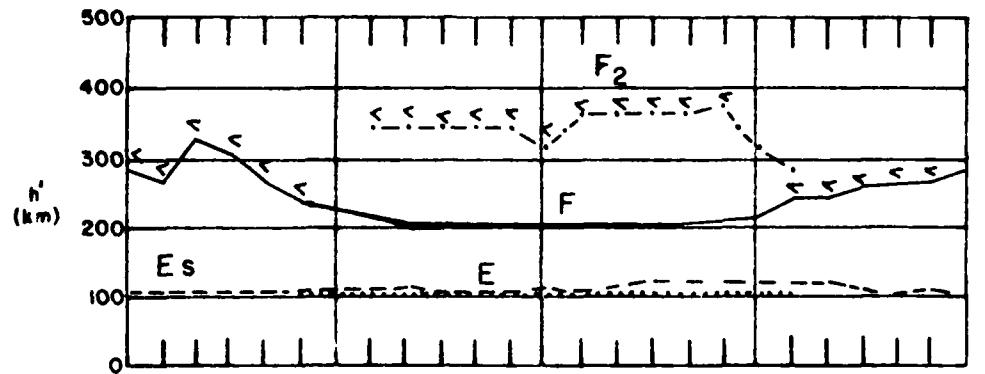
AUG 1977
GOOSE BAY, LABRADOR
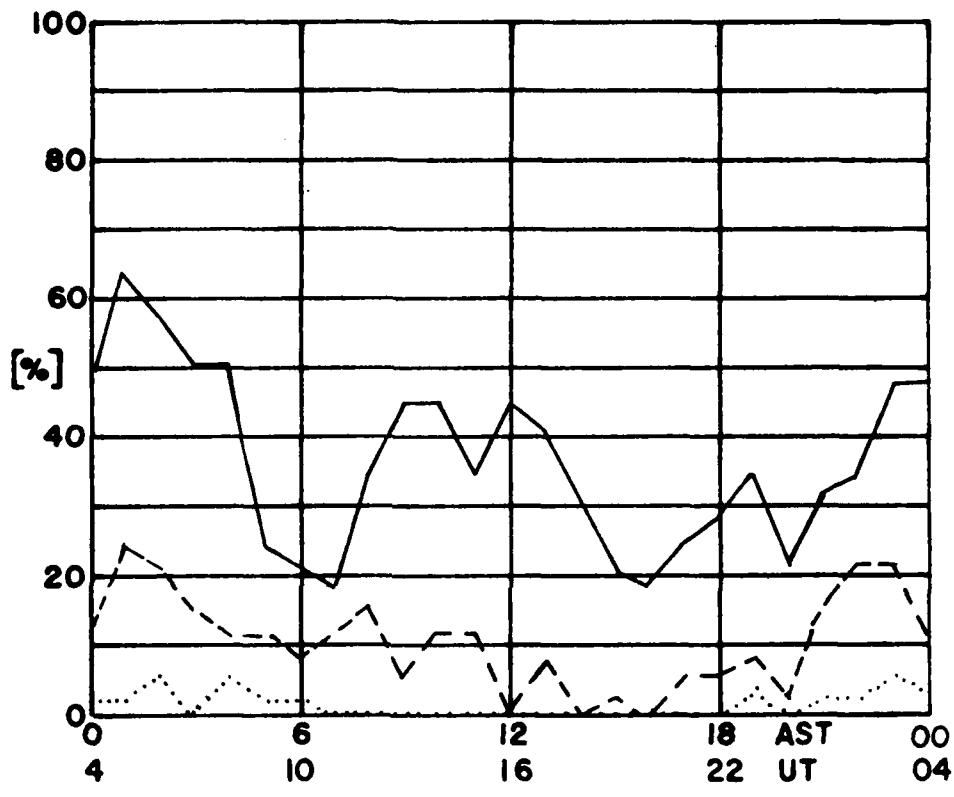
PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

64

MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR

AUGUST 1977
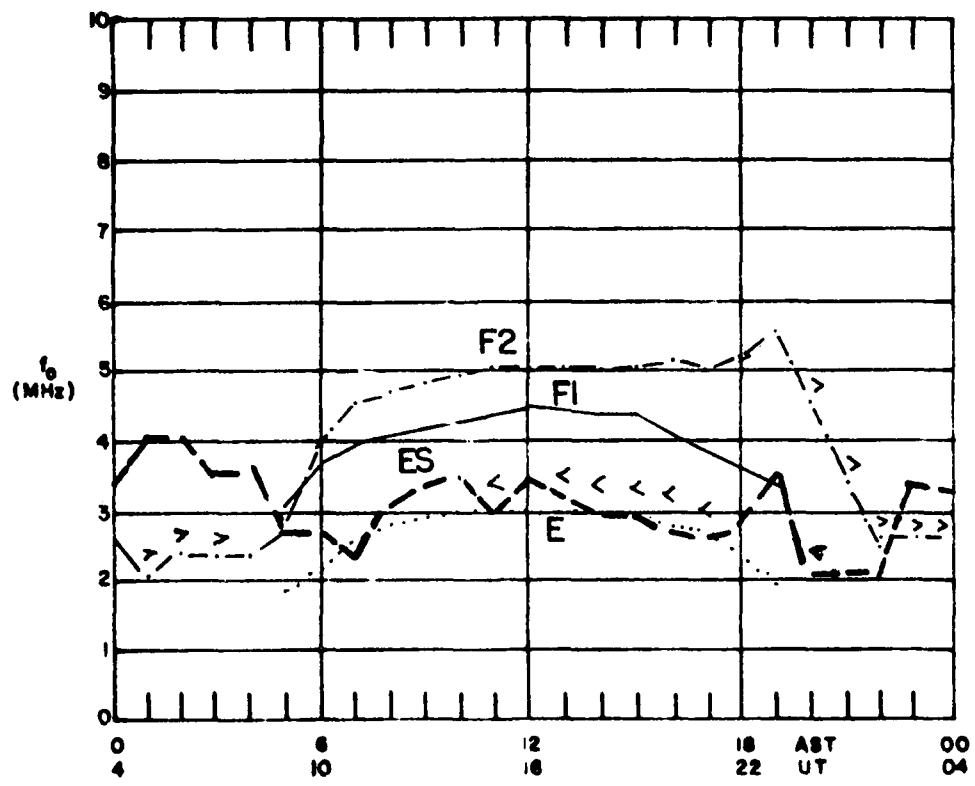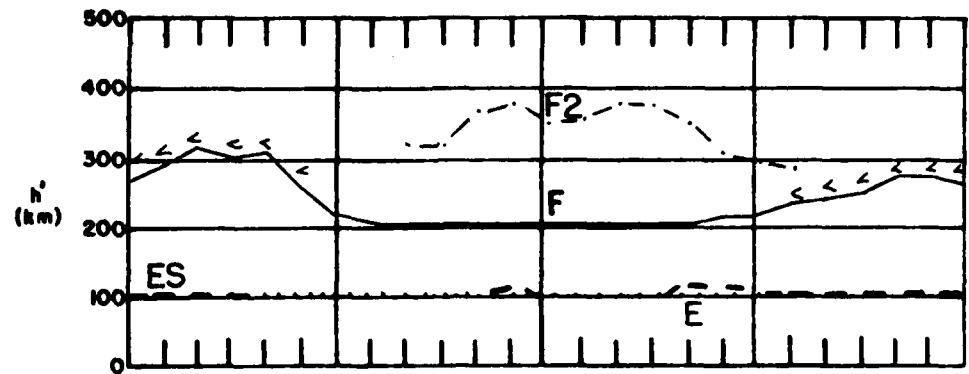
SEPT 1977
GOOSE BAY, LABRADOR
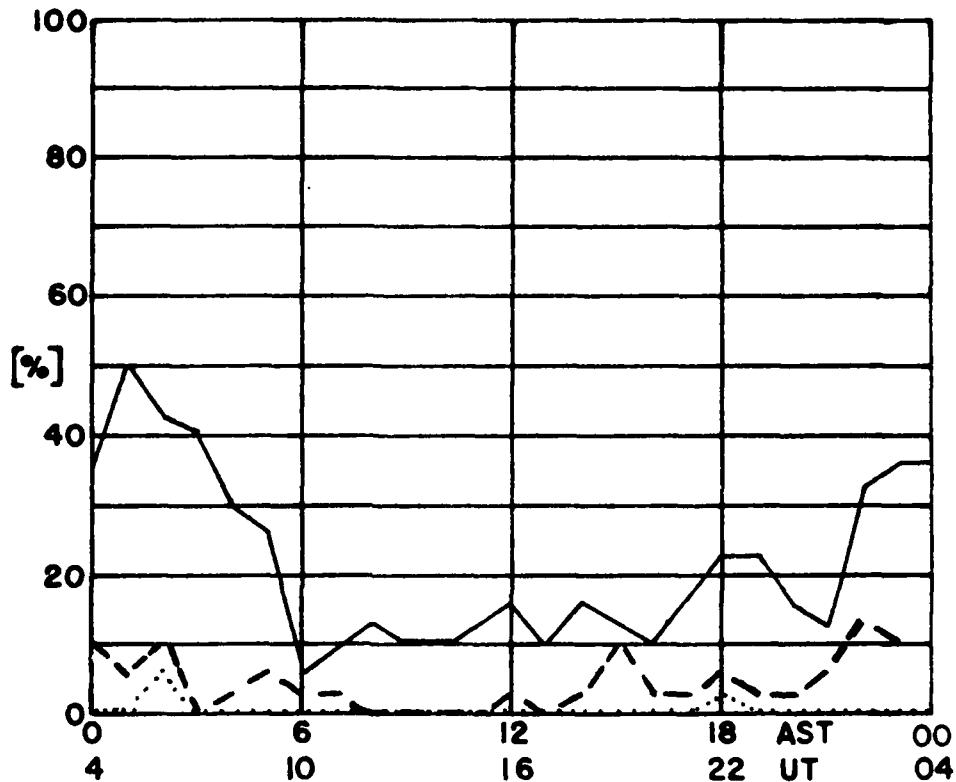
LIMITING FREQUENCY = 3MHz ————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

66

MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR

SEPTEMBER 1977

67
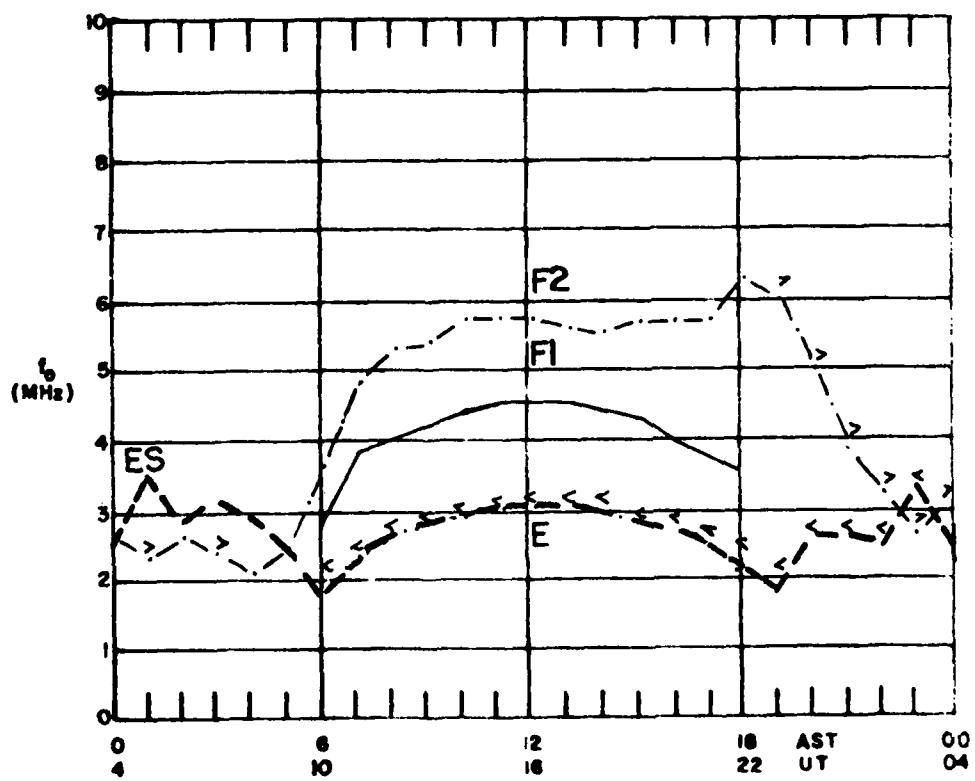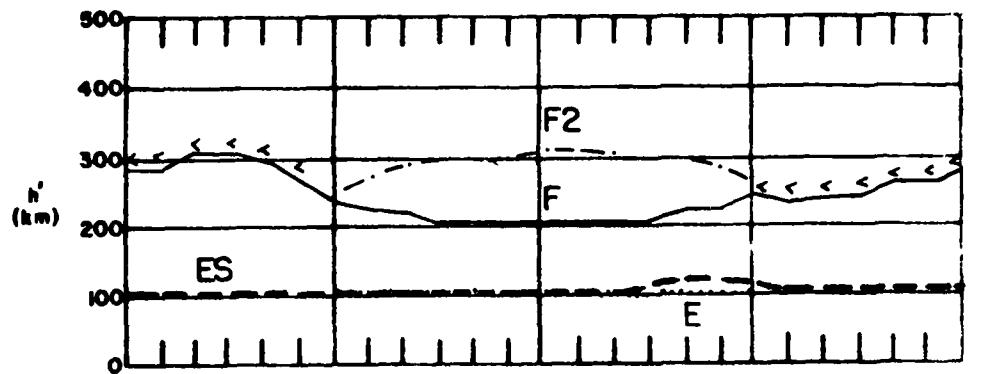
OCT 1977
GOOSE BAY, LABRADOR
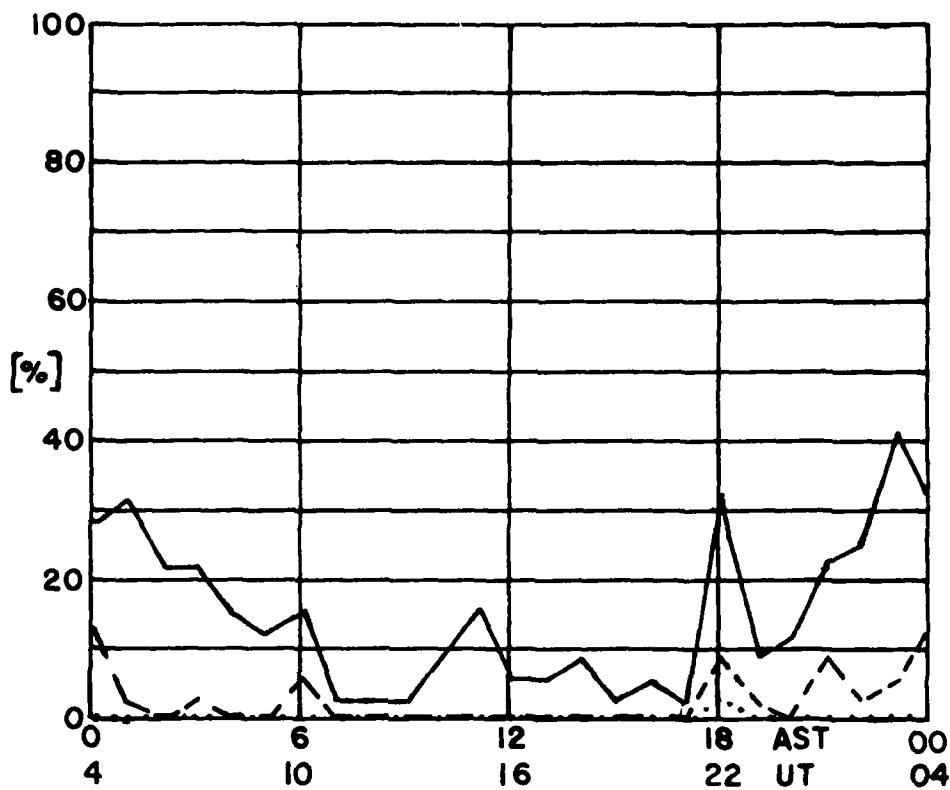
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ··············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

68

MEDIAN VALUES OF h' AND f_o AT GOOSE BAY, LABRADOR FOR
OCTOBER 1977
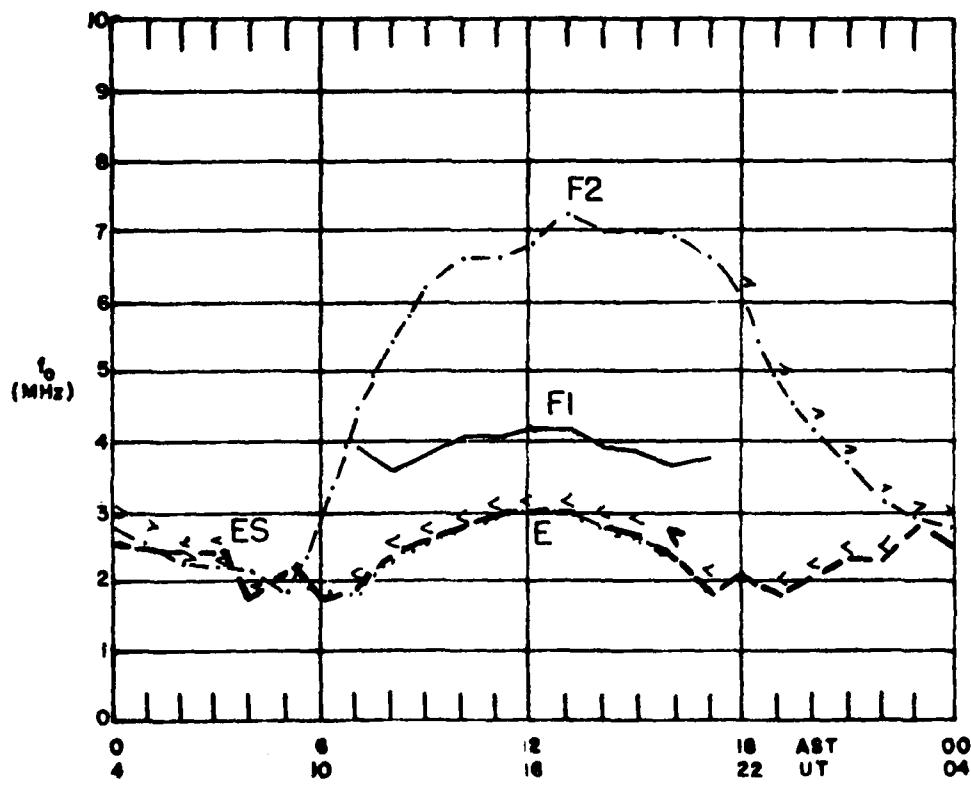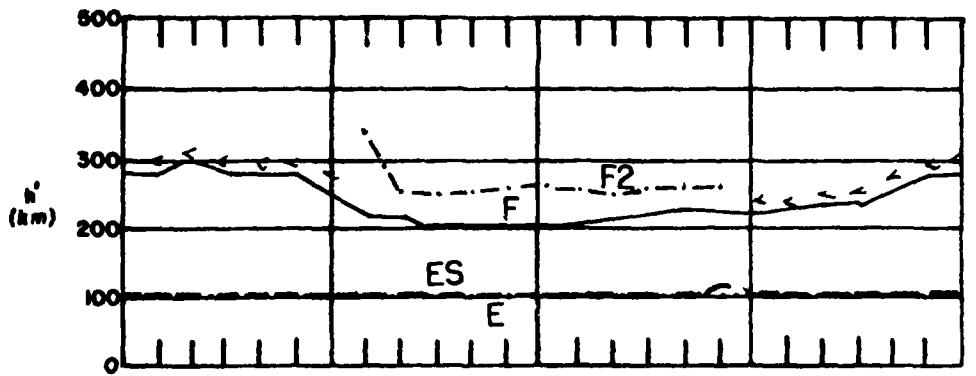
GOOSE BAY, LABRADOR
NOVEMBER 1977
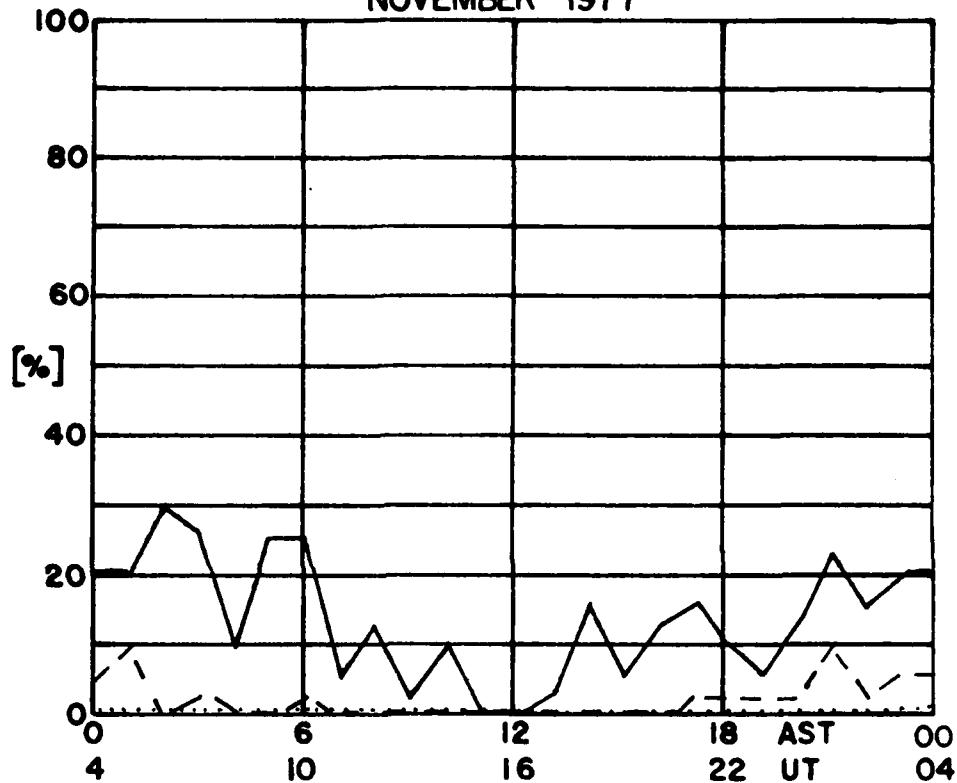
LIMITING FREQUENCY = 3MHz ————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

70

MEDIAN VALUES OF h' AND f_0 AT GOOSE BAY, LABRADOR FOR
NOVEMBER 1977

71
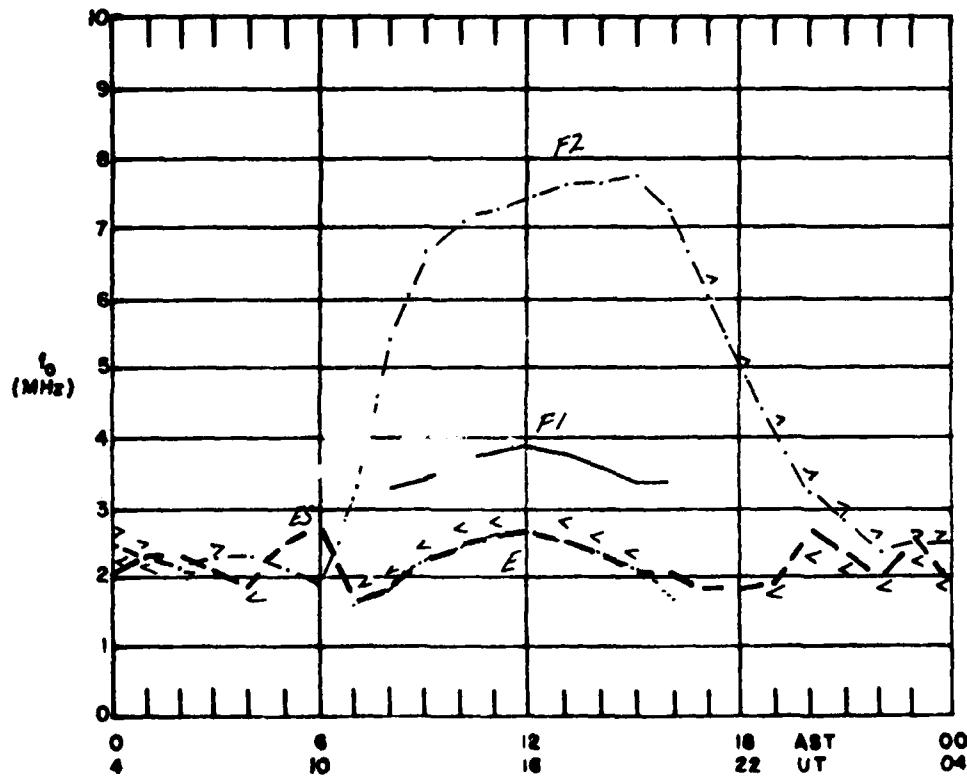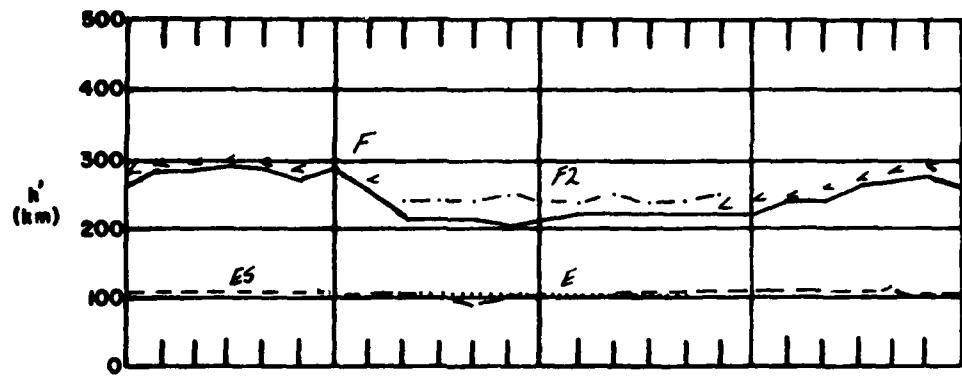
DECEMBER 1977

GOOSE BAY, LABRADOR
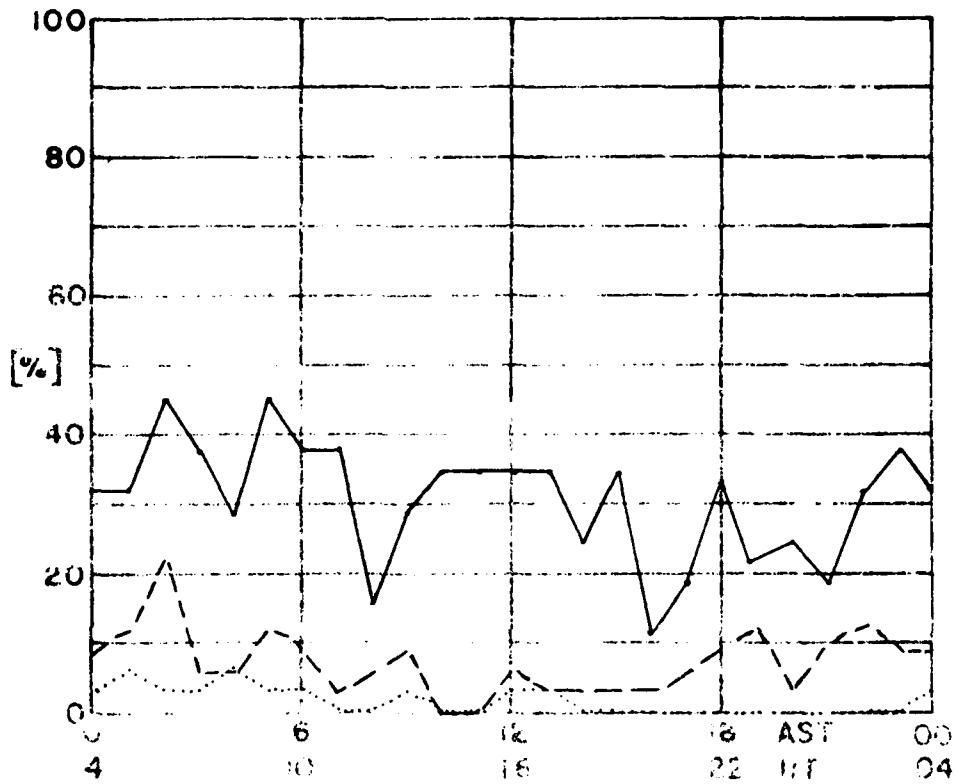
LIMITING FREQUENCY 3MHz ── ──
LIMITING FREQUENCY 5MHz ── ── ──
LIMITING FREQUENCY 7MHz ············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

72

MEDIAN VALUES OF h' AND f$_0$ AT GOOSEBAY, LABRADOR FOR DECEMBER 1977


73
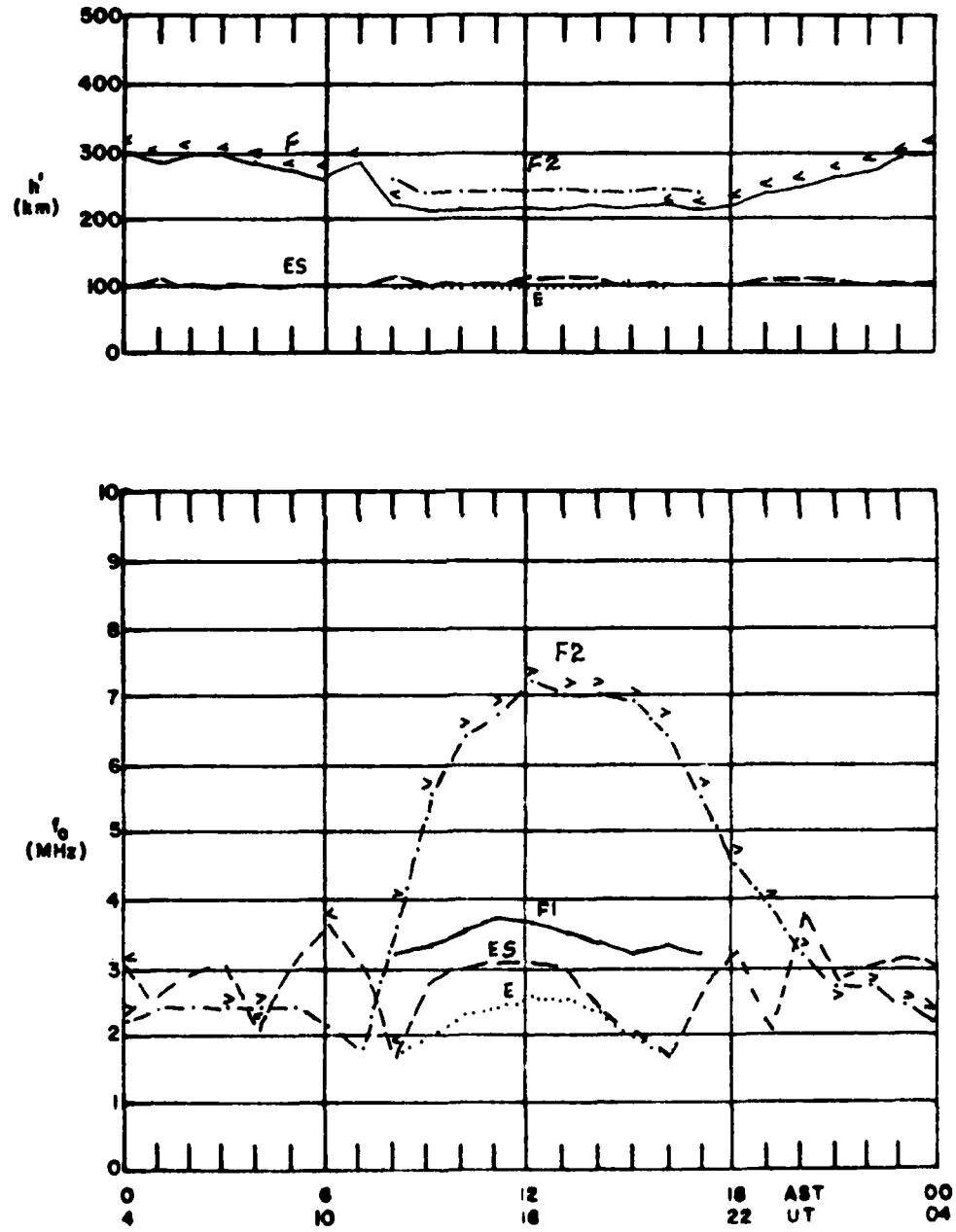
JANUARY 1978

GOOSE BAY, LABRADOR
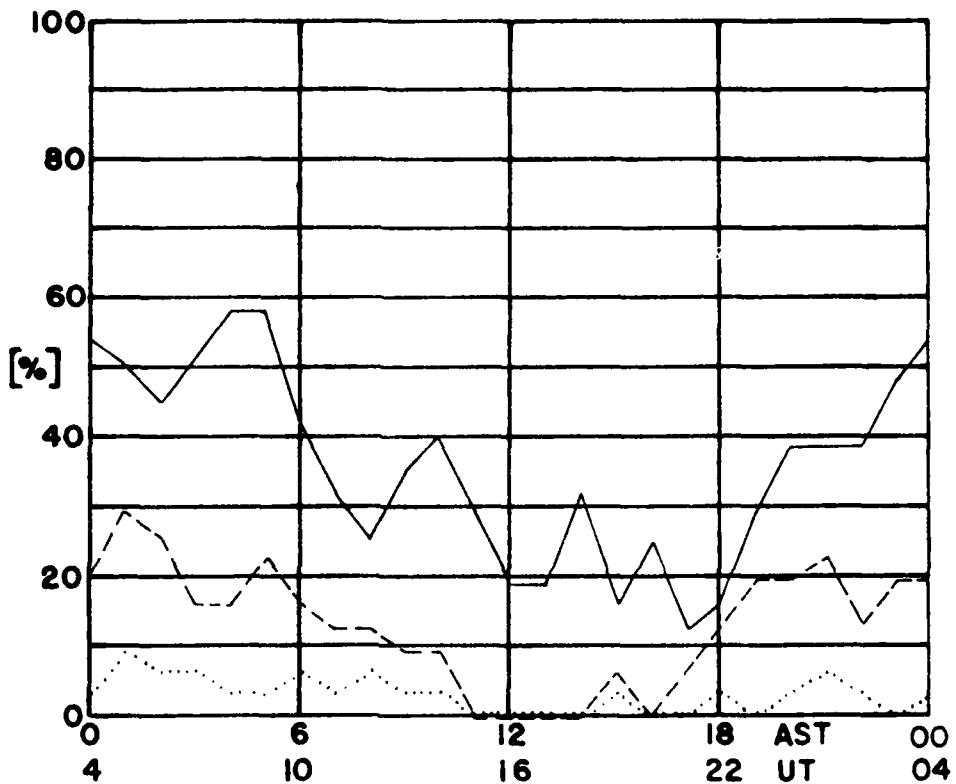
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz —— —— —— ——

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

74

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR JANUARY 1978

75
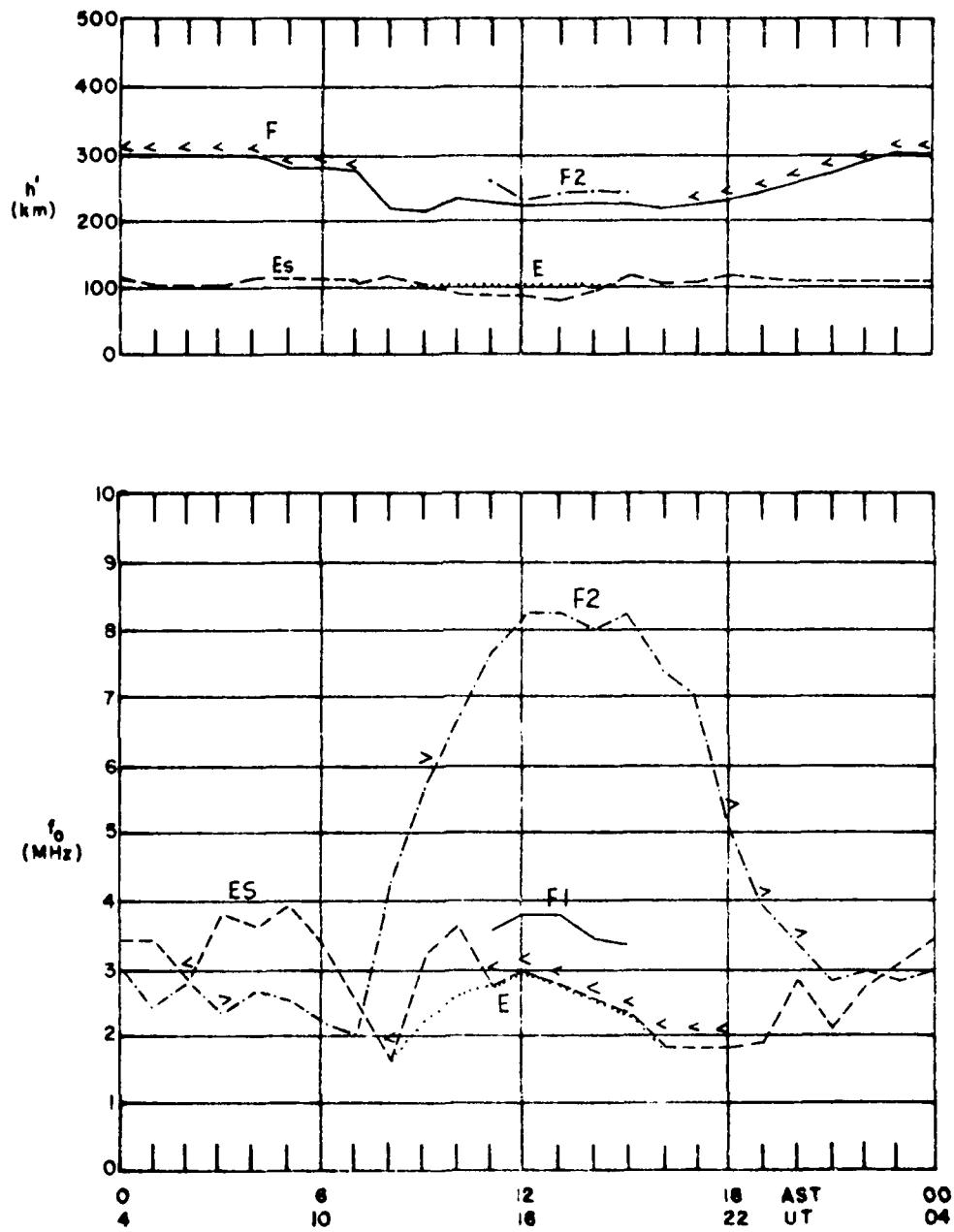
FEBRUARY 1978
GOOSE BAY, LABRADOR
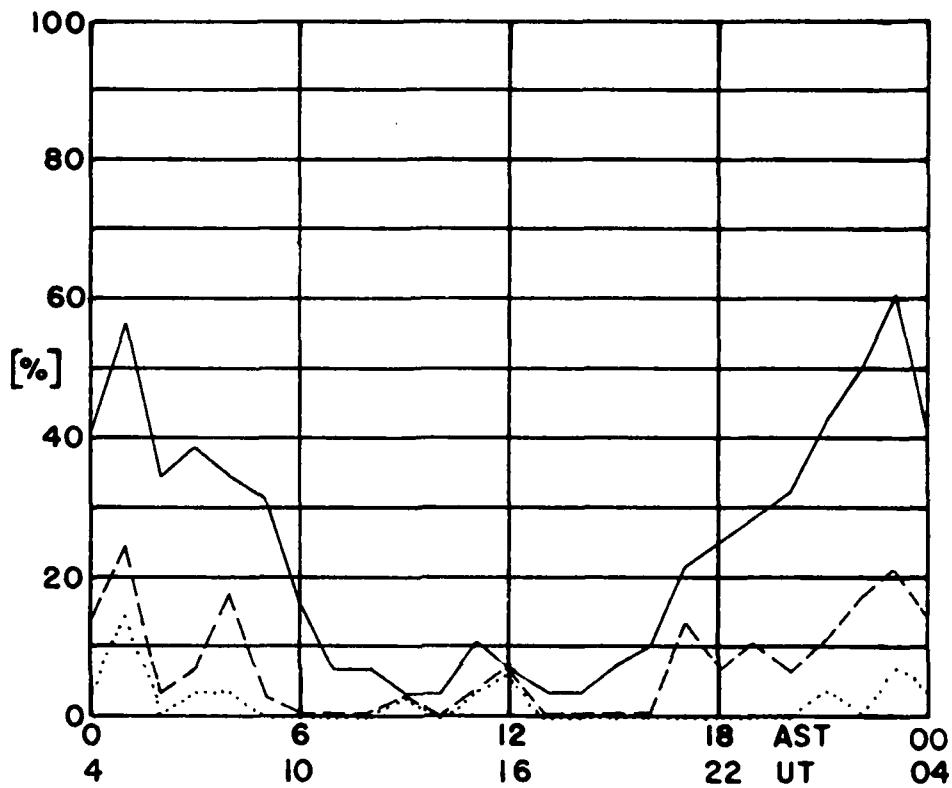
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ················

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

76

MEDIAN VALUES OF h' AND f_0 AT GOOSEBAY, LABRADOR FOR FEBRUARY 1978
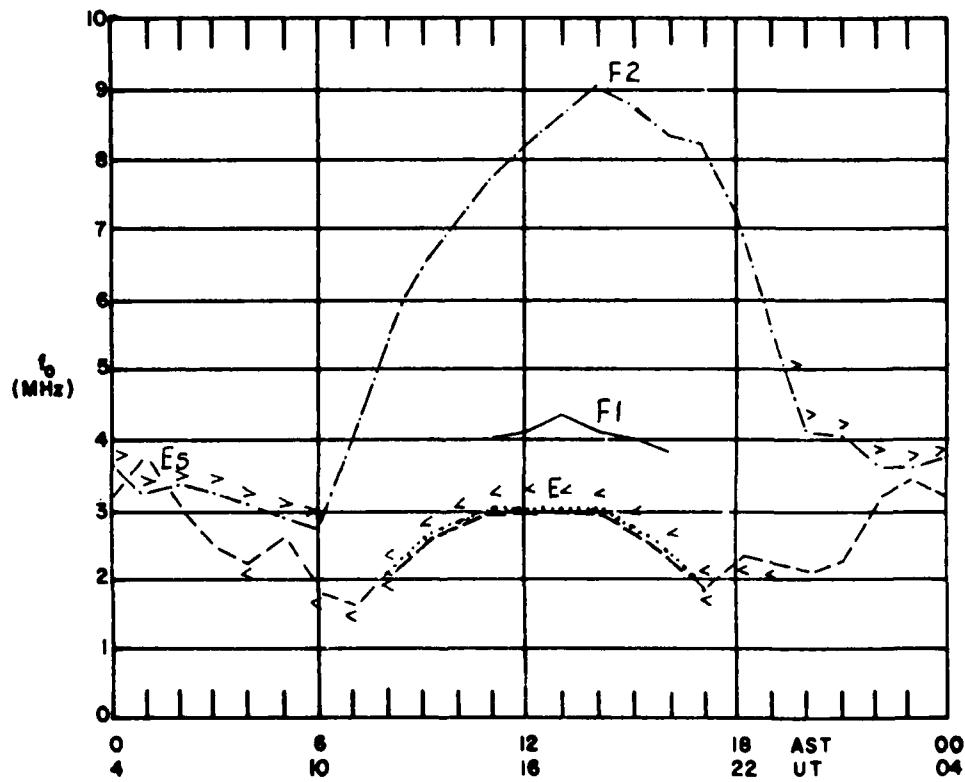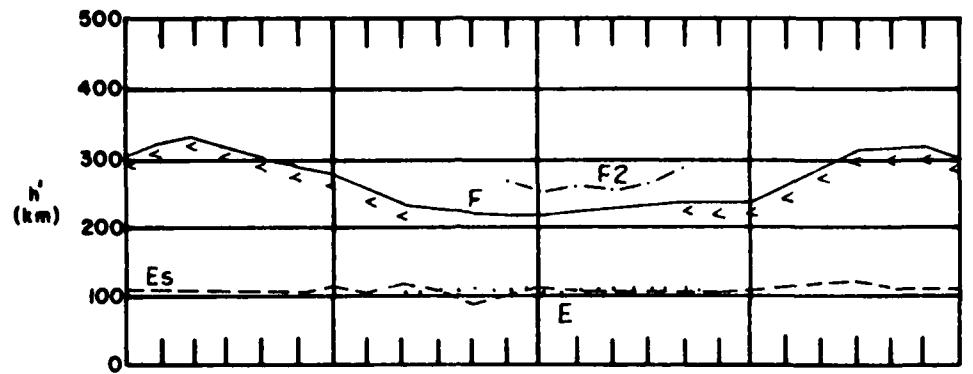
MARCH 1978

GOOSE BAY, LABRADOR
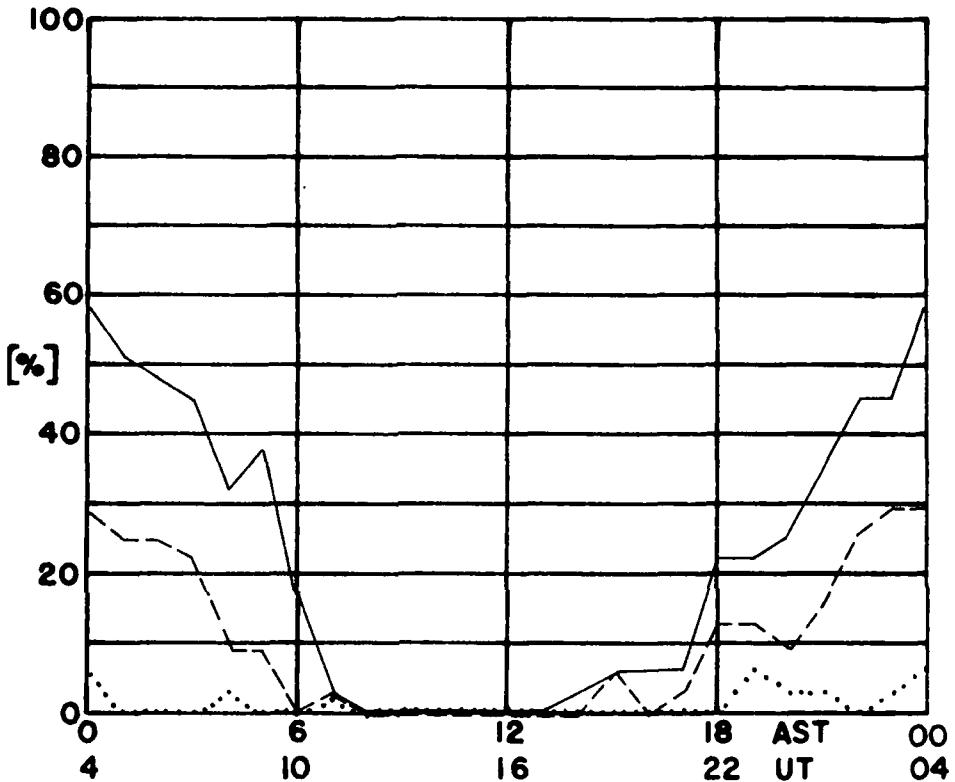
LIMITING FREQUENCY = 3MHz ——————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
f_oE_s IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR MARCH 1978

79
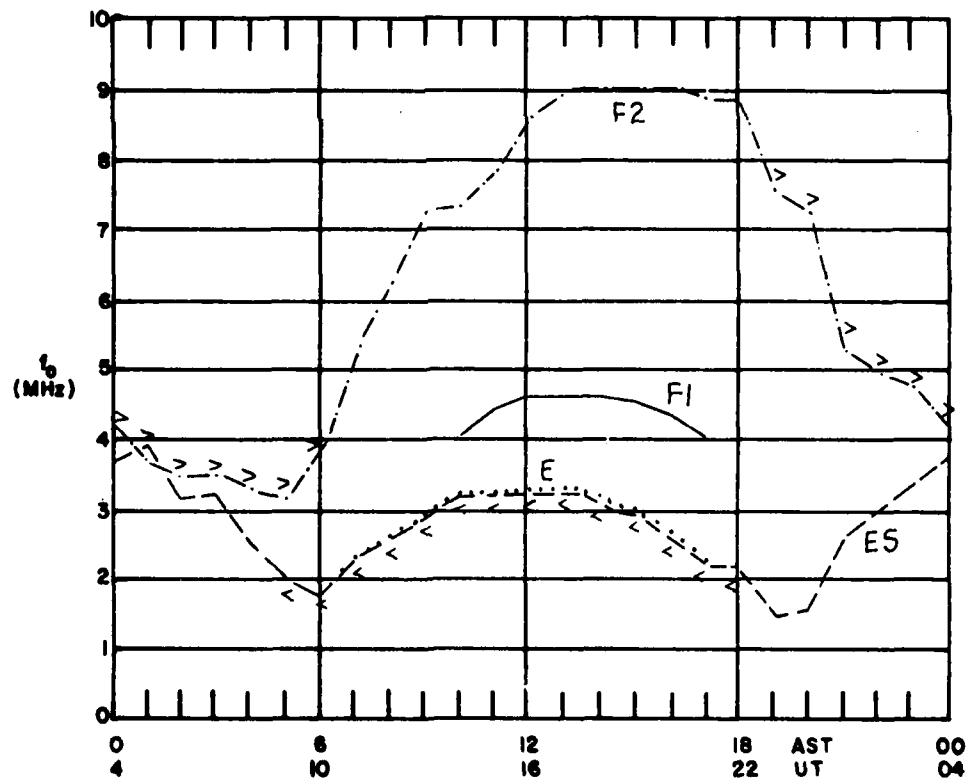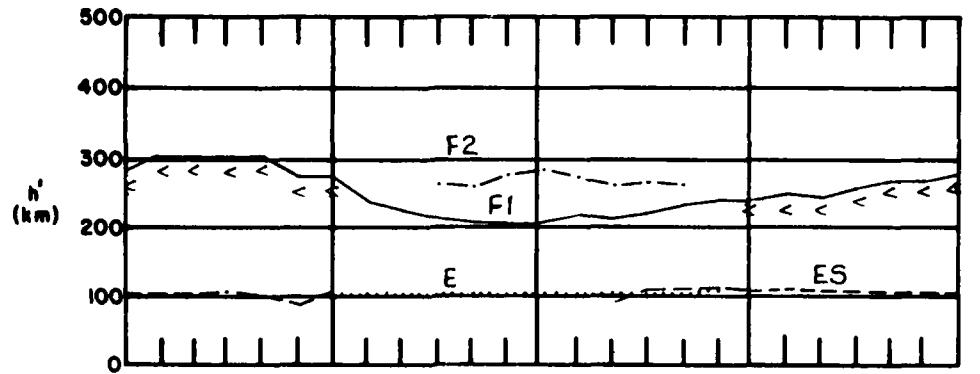
APRIL 1978
GOOSE BAY, LABRADOR
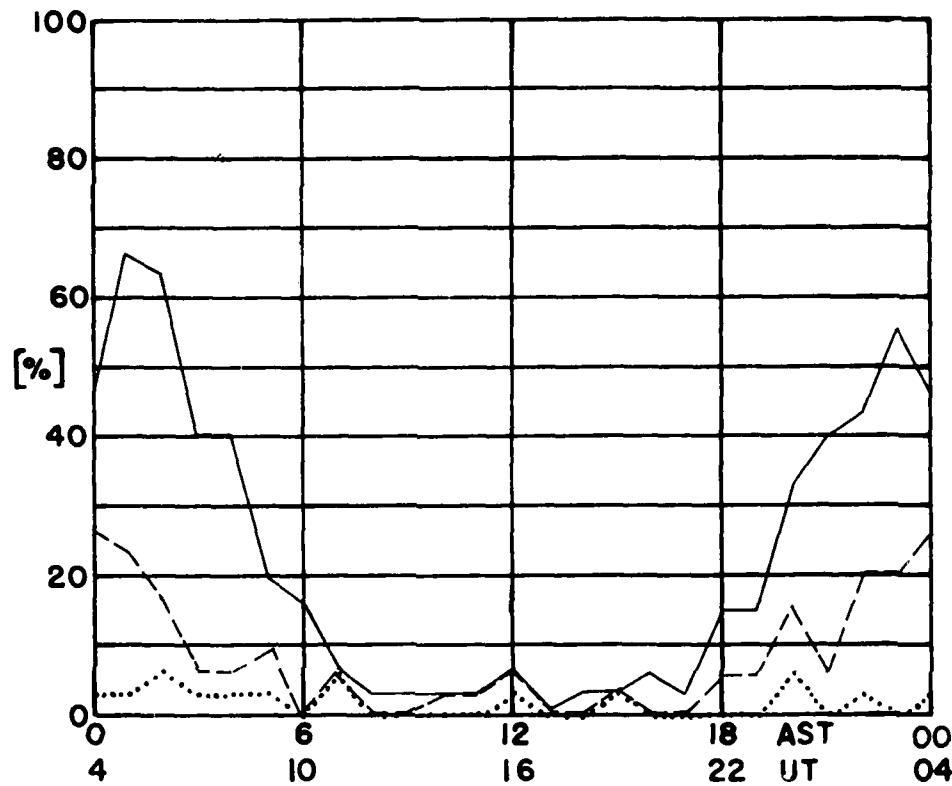
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ··············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

80

MEDIAN VALUES OF h'AND f_0 AT GOOSEBAY, LABRADOR FOR APRIL 1978

81
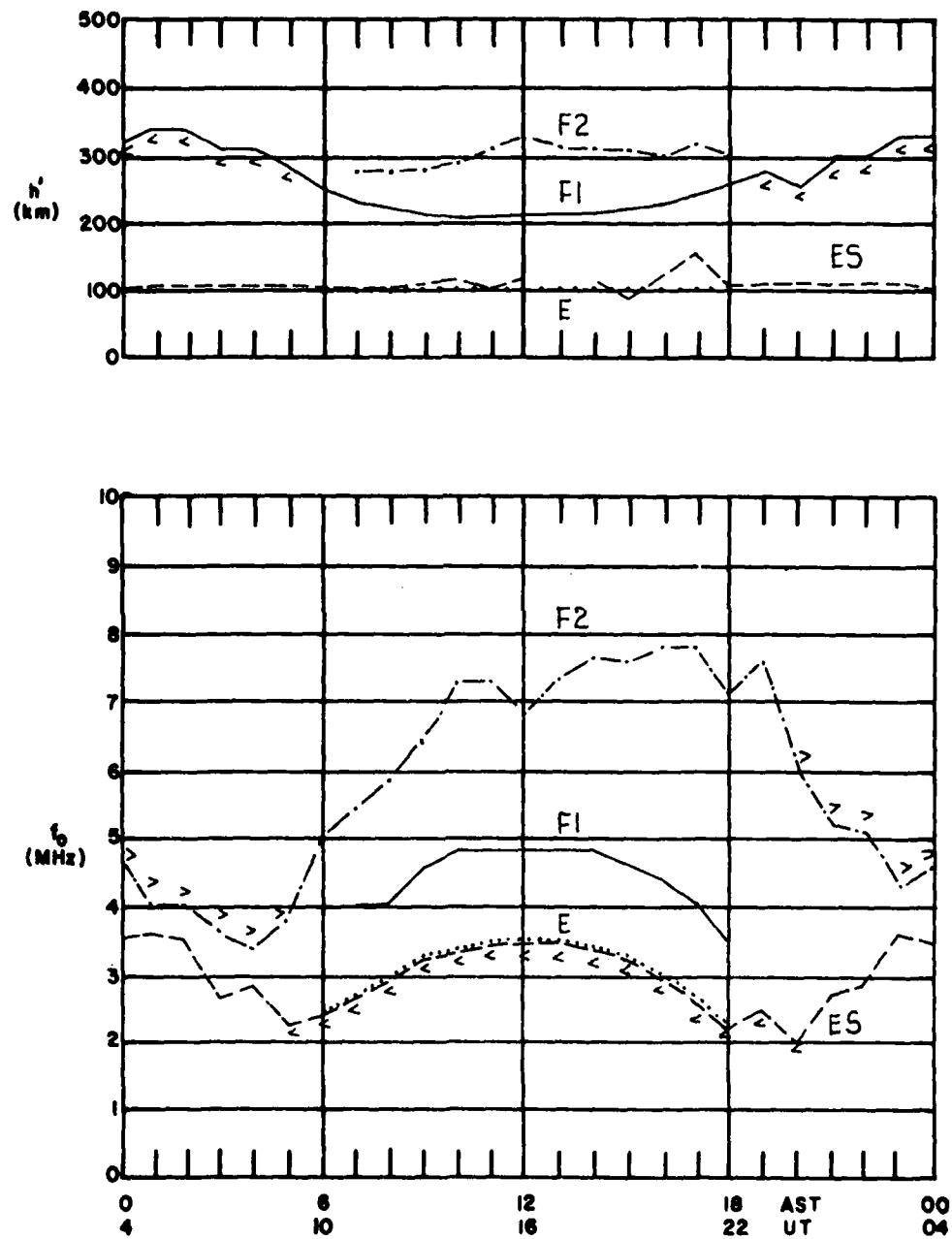
## MAY 1978

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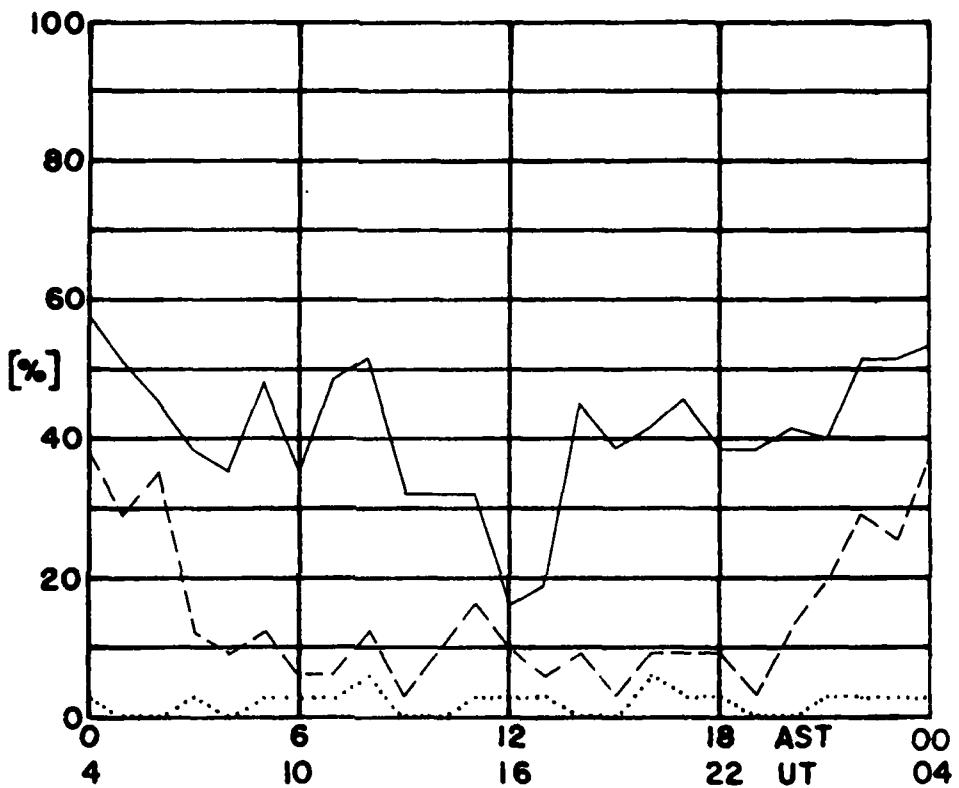
LIMITING FREQUENCY = 3MHz ——————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

82

MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR MAY 1978
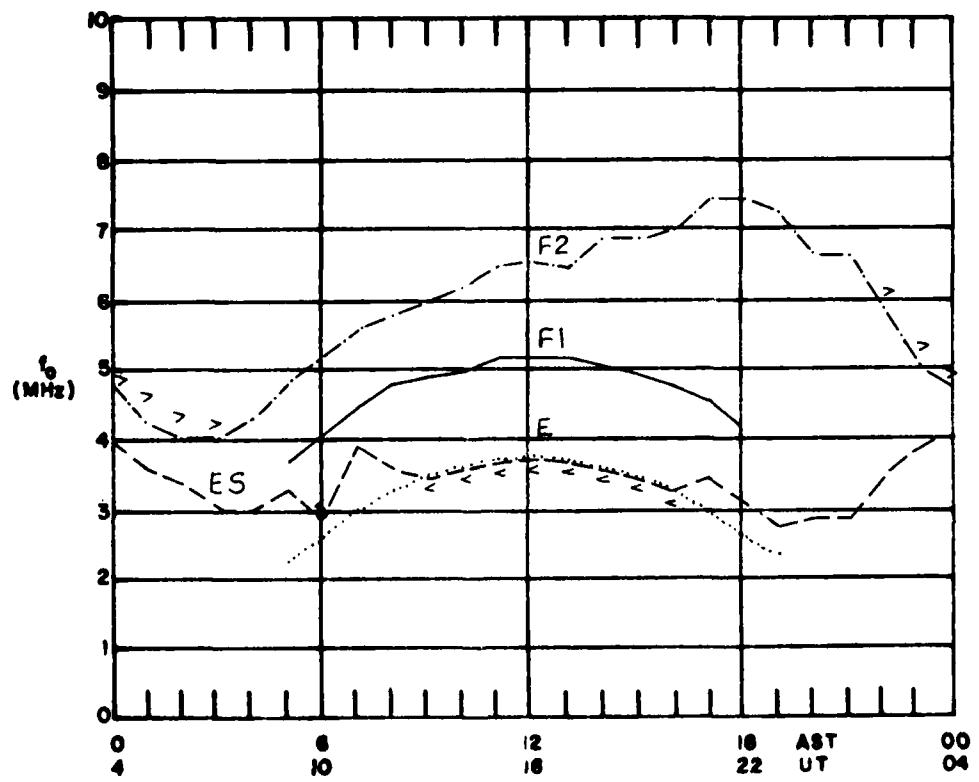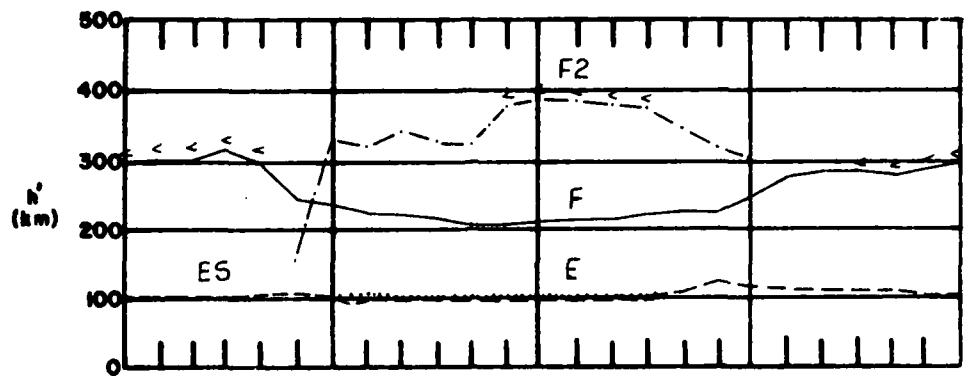
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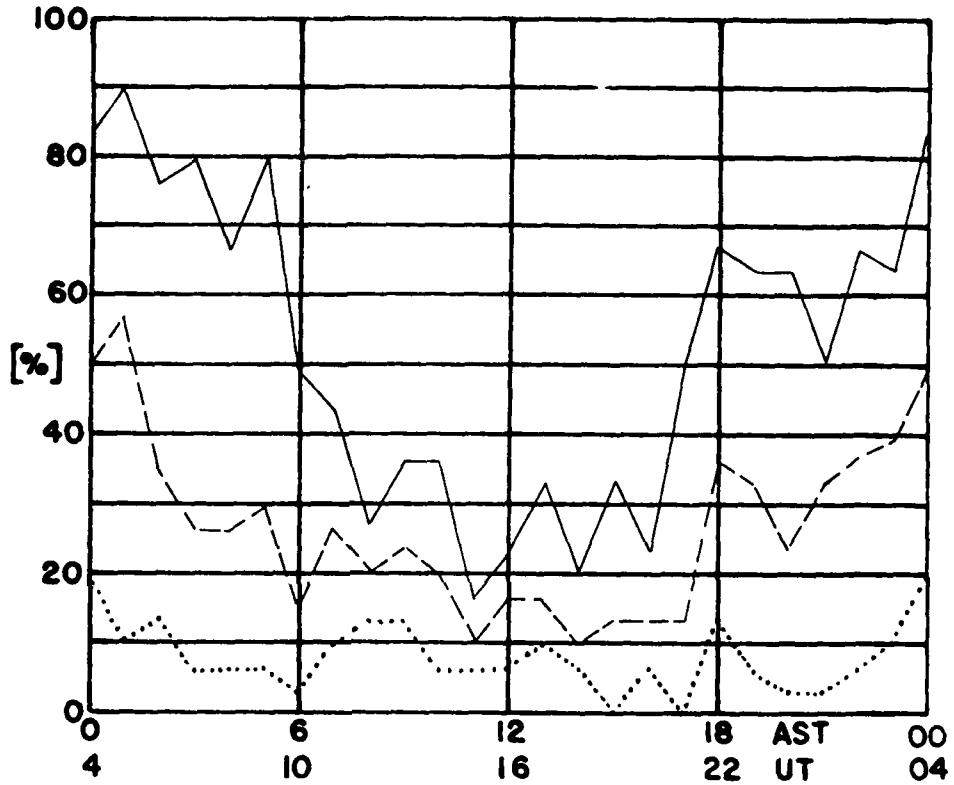
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ···············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

84

MEDIAN VALUES OF h' AND f_o AT GOOSEBAY, LABRADOR FOR JUNE 1978
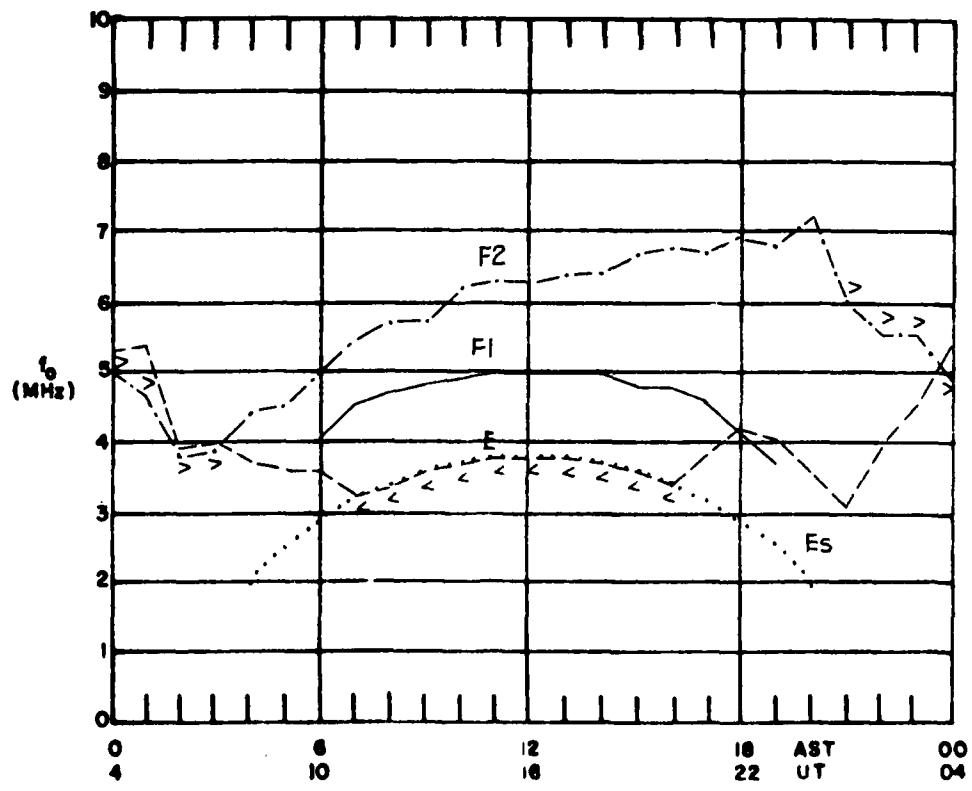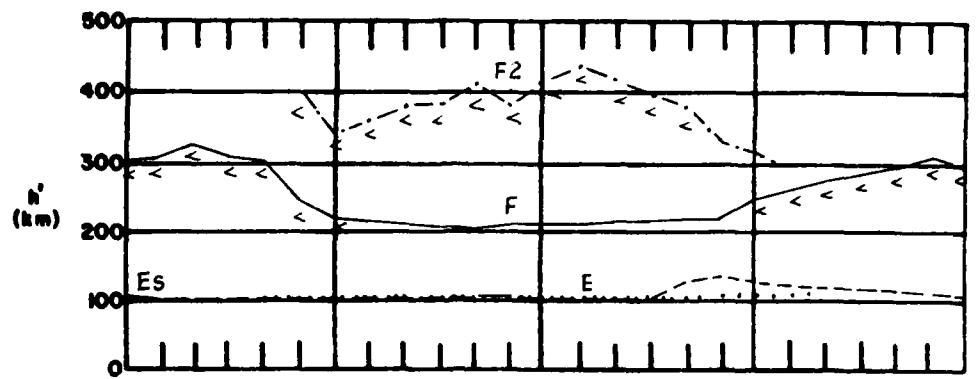
JULY 1978

GOOSE BAY, LABRADOR
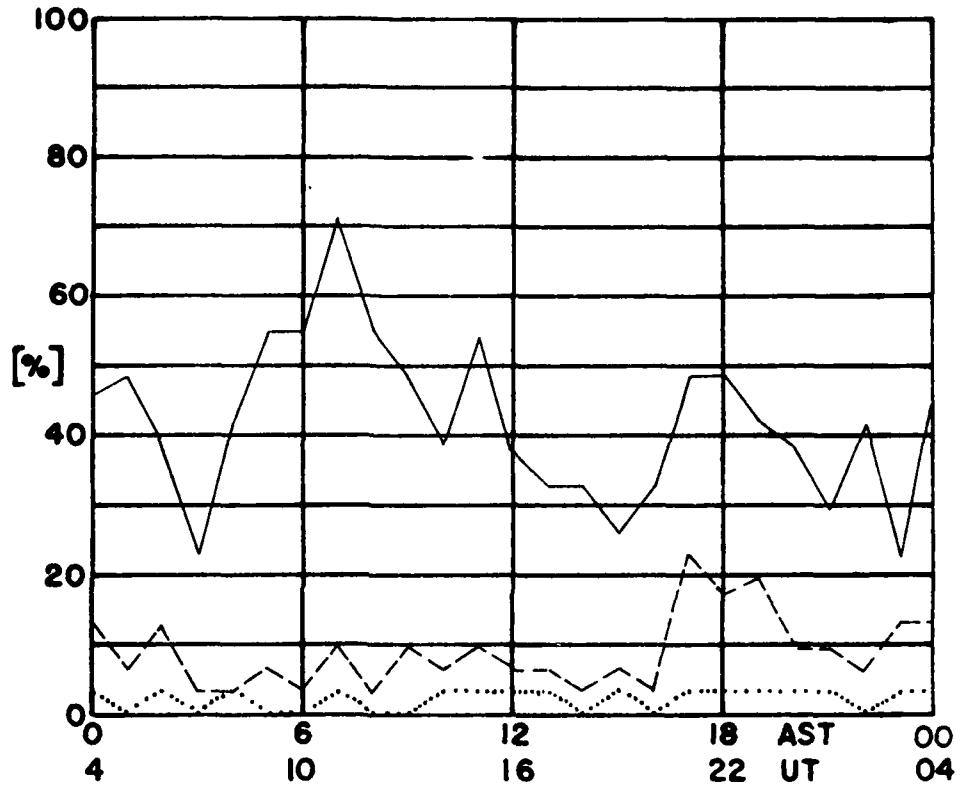
LIMITING FREQUENCY = 3 MHz ————

LIMITING FREQUENCY = 5 MHz — — — — —

LIMITING FREQUENCY = 7 MHz ············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR JULY 1978
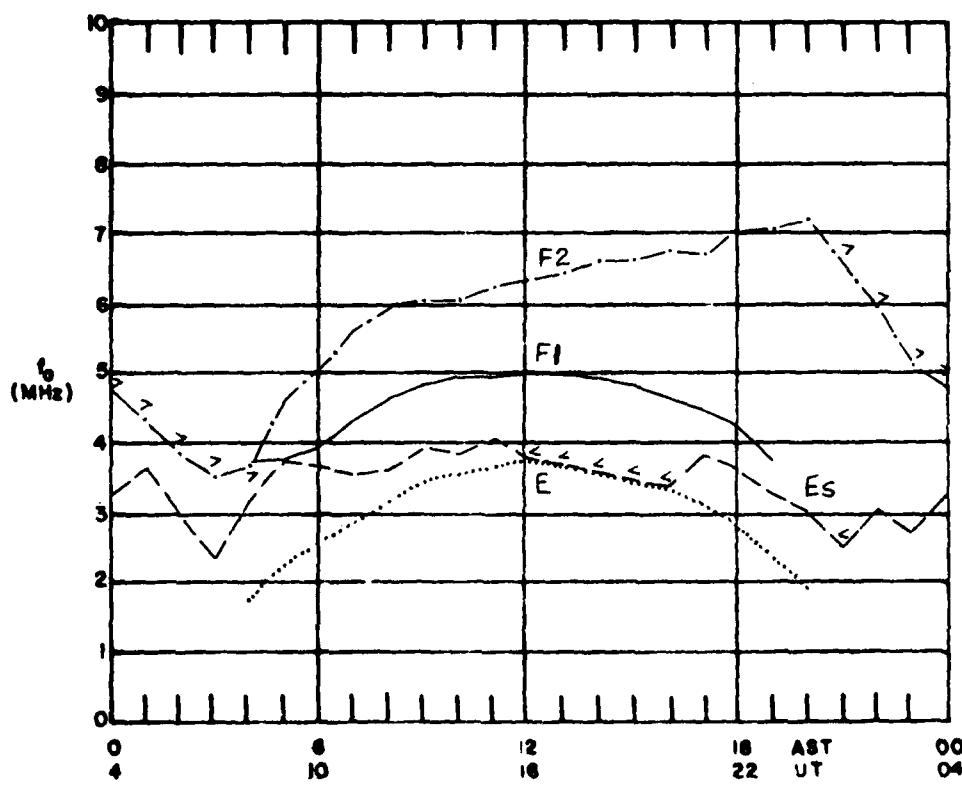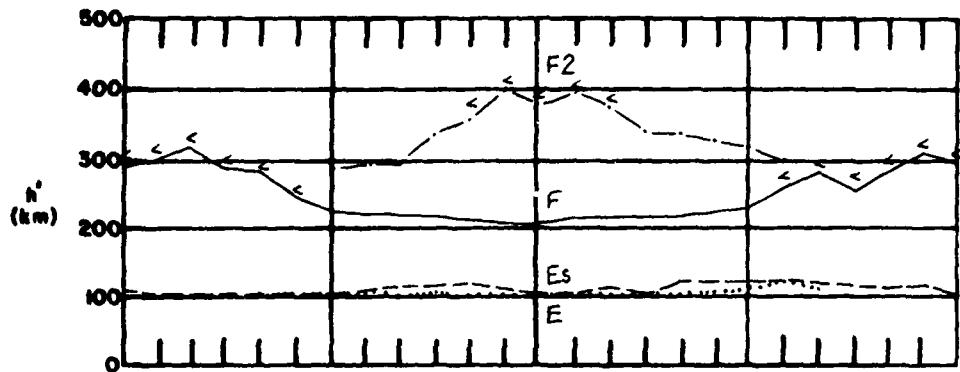
AUGUST 1978
GOOSE BAY, LABRADOR

LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES OF h' AND f$_0$ AT GOOSEBAY, LABRADOR FOR AUGUST 1978

89
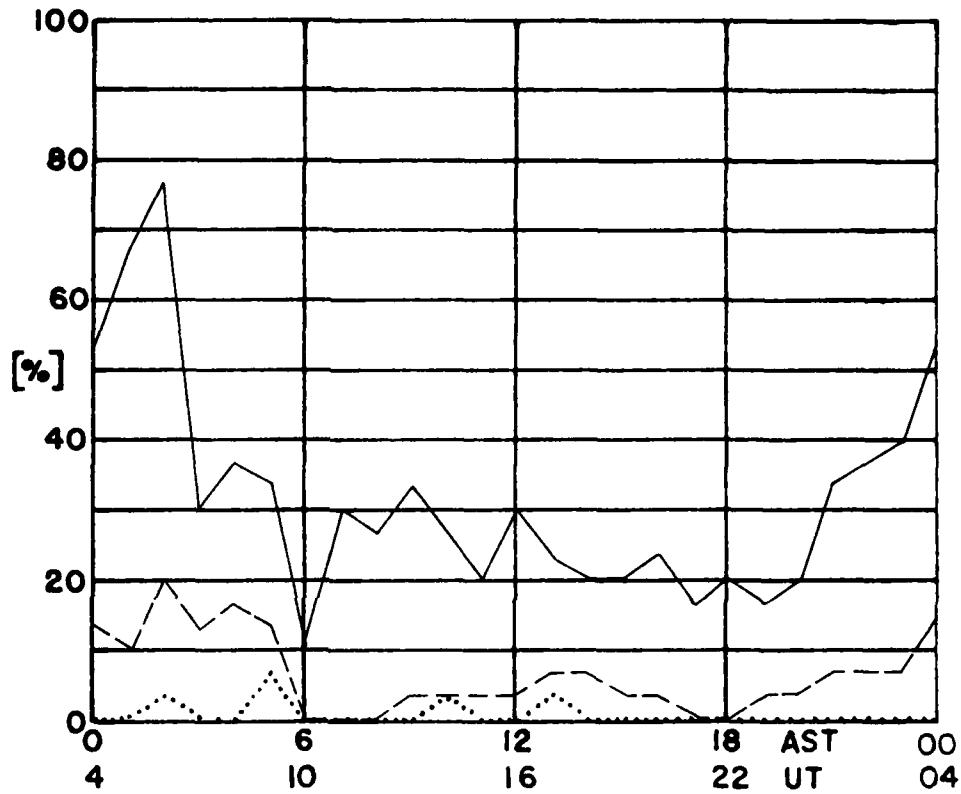
SEPTEMBER 1978

GOOSE BAY, LABRADOR

LIMITING FREQUENCY = 3 MHz ————

LIMITING FREQUENCY = 5 MHz — — — — —

LIMITING FREQUENCY = 7 MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

OCTOBER 1978
GOOSE BAY, LABRADOR

LIMITING FREQUENCY = 3MHz ——————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

92

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR OCTOBER 1978

NOVEMBER 1978

GOOSE BAY, LABRADOR
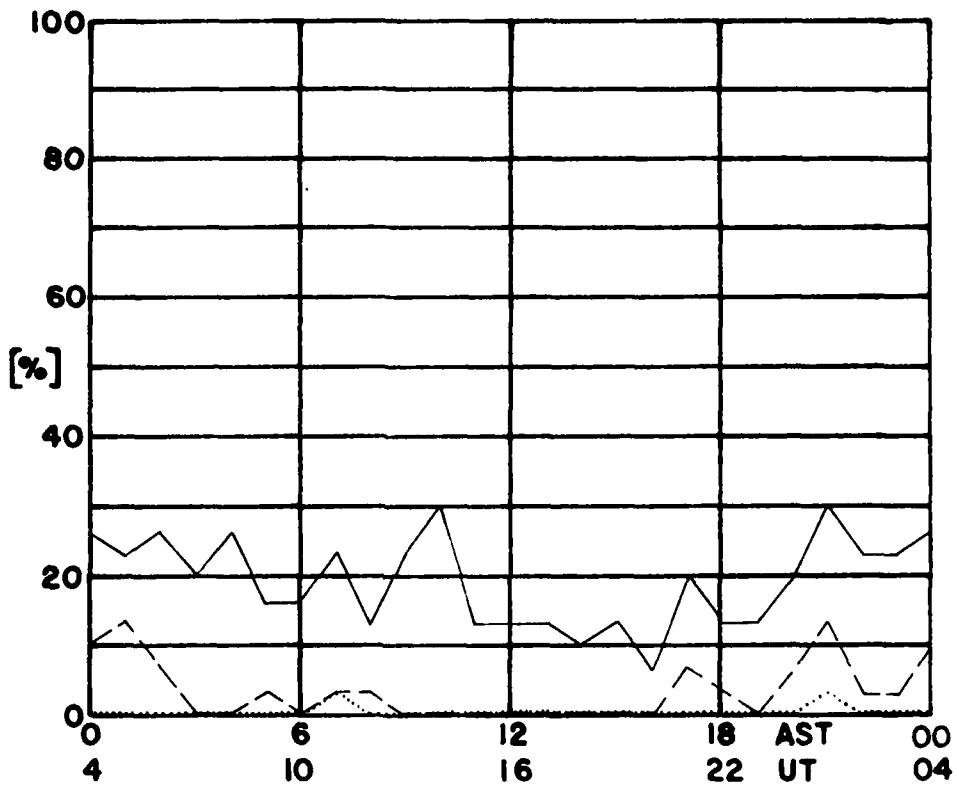
LIMITING FREQUENCY = 3MHz ———————

LIMITING FREQUENCY = 5MHz — — — — —

LIMITING FREQUENCY = 7MHz ··············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_0 E_s$ IS GREATER THAN THE LIMITING FREQUENCY

MEDIAN VALUES of h' AND f₀ AT GOOSE BAY, LABRADOR FOR
NOVEMBER 1978
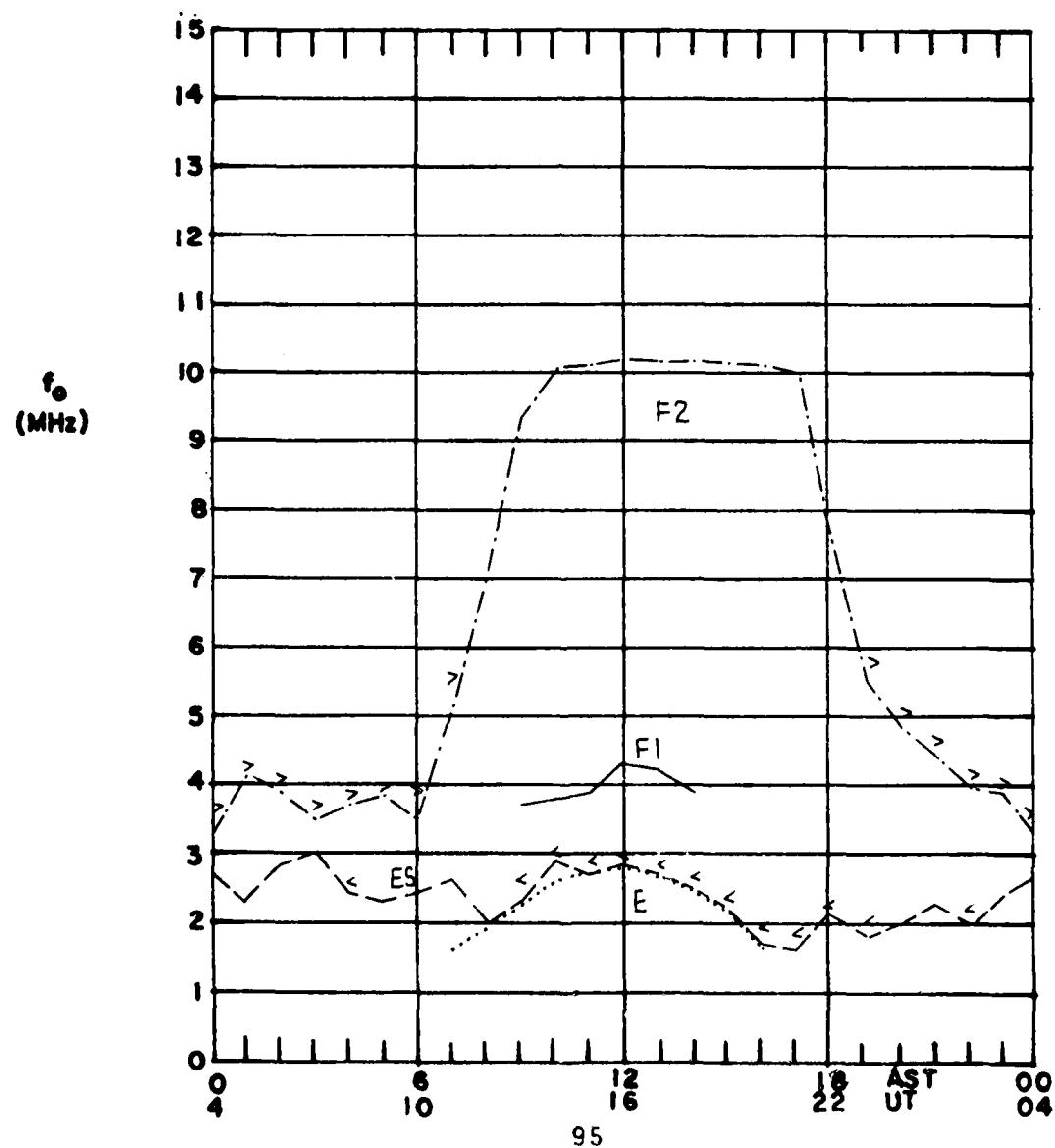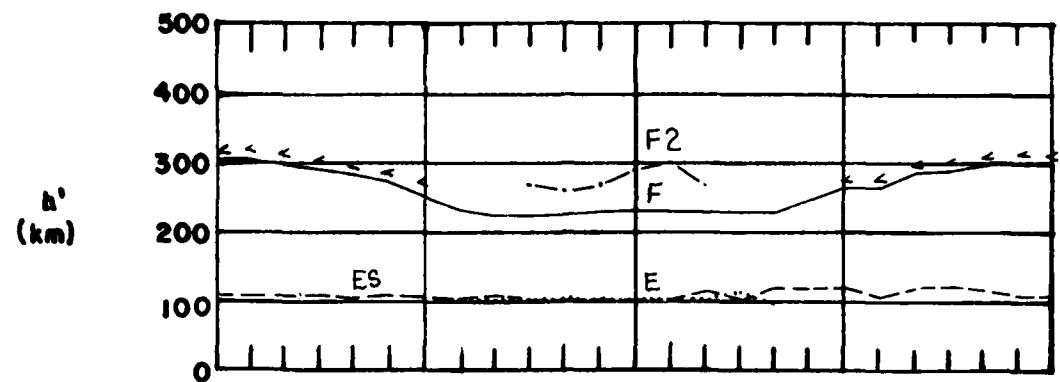
DECEMBER 1978

GOOSE BAY, LABRADOR
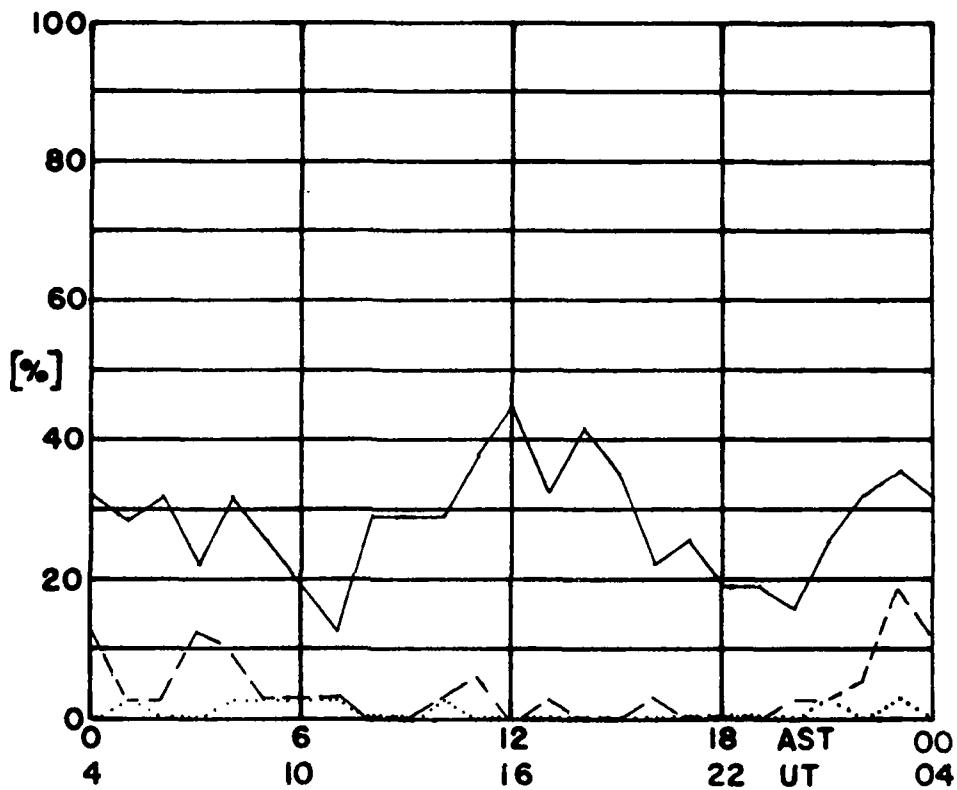
LIMITING FREQUENCY = 3MHz ————————

LIMITING FREQUENCY = 5MHz — — — — — —

LIMITING FREQUENCY = 7MHz ·············

PERCENTAGE OF TOTAL TIME DURING WHICH
$f_o E_s$ IS GREATER THAN THE LIMITING FREQUENCY

96

MEDIAN VALUES OF h' AND f₀ AT GOOSEBAY, LABRADOR FOR DECEMBER 1978
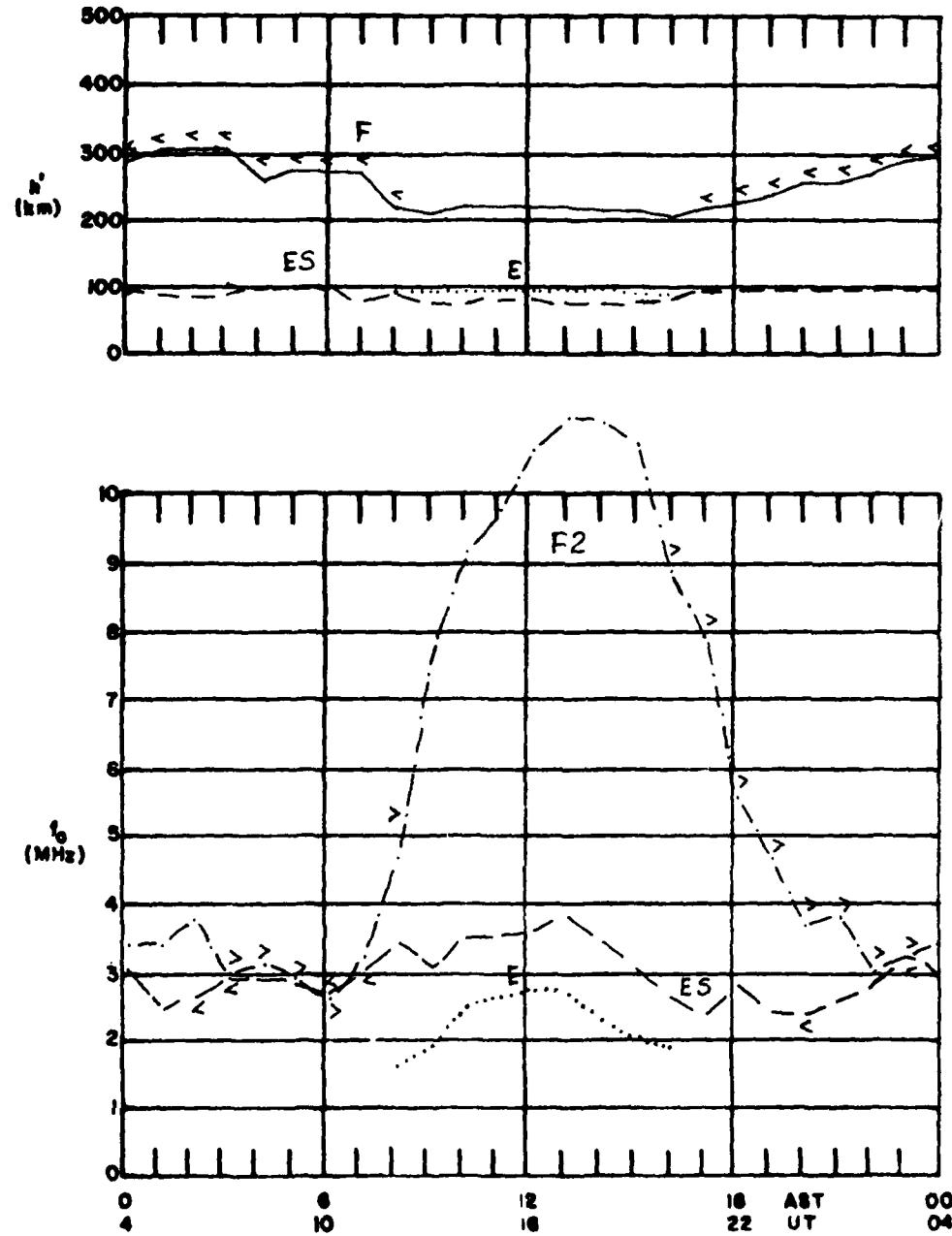
APPENDIX   B

PAPERS AND ABSTRACTS

Papers and Abstracts which were in part supported under Con-
tract F19628-78-C-0085 and the preceding Contract F19628-77-
C-0024 and had not been officially submitted to the Air Force.

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Paper Reprinted from
Conference Proceedings No.263

SPECIAL TOPICS
IN HF PROPAGATION

NORTH ATLANTIC TREATY ORGANIZATION

DIGITAL ON-LINE PROCESSING AND DISPLAY
OF MULTIPARAMETER HF TRANSMISSION DATA

K. Bibl and B. W. Reinisch
University of Lowell
Center for Atmospheric Research
Lowell, Massachusetts, U.S.A.

SUMMARY

Amplitude, phase, angle of arrival, polarization, frequency shift and signal travel time of a radio wave are simultaneously measured as functions of time and frequency in a new digital ionosonde, the Digisonde 128PS.

For the study of the structure and motions of the ionosphere and its influence on Over-the-Horizon detection systems, on sea-state measurements, on direction and location finding methods and on communication systems a selection of the measurable parameters is recorded and displayed in real time with the necessary resolution. Two main modes of operation are described, the ionogram mode using a Maximum Amplitude scheme for data compression and the Doppler-Drift mode using preselected frequencies and range bins for data compression.

Many applications in new fields are anticipated in addition to the thorough understanding of the ionosphere, its sources and its forces.

1.   INTRODUCTION

Radio waves are characterized by amplitude, phase, angle of arrival, polarization, frequency shift and signal travel time. All these wave parameters are measured as functions of time and frequency and displayed in real-time in a new digital ionosonde, the Digisonde 128PS. For the study of the structure and the motion of a dispersive medium, like the ionosphere, and for a full analysis of the influence of the ionosphere on Over-the-Horizon detection systems, on sea-state measurements, on direction and location finding methods and on communication systems a digital radio sounder is employed with pulsed carrier frequencies scanning in steps through a large frequency band. Frequency scanning adds an important parameter to the wave characteristics of a conventional Radar system.

2.   SYSTEM DESCRIPTION

As a scientific instrument, but useful for many operational tasks, we have developed a digital ionosonde which uses a large antenna array in a scanning or in a beam-forming mode. The Digisonde 128PS (K. Bibl and B. W. Reirisch, 1978) simultaneously integrates the echo amplitudes in a phase coherent mode at many Doppler frequencies, and for all chosen antennas or beam-directions. Echoes from 24 antennas can at once be spectrum analyzed in 128 coherent channels, or 1f spectral lines can be monitored for 128 range bins. Many other combinations of range windows, frequencies, polarizations, spectral channels and incidence angles can be processed simultaneously. Using the time between the transmitted pulses to measure complex spectrum amplitudes in up to 256 range bins (time sectors) requires a very fast on-line spectrum analyzer. The Processing Controller of the Digisonde forms the products between the sine and cosine samples of the high frequency (HF) signal and the trigonometric spectral function (of three averaged spectral lines) at a rate of 1 MHz. But such a large amount of data can not be handled on a continuous basis. We therefore operate the system in one of two data compression schemes: the Ionogram Mode with the Maximum-Amplitude Method, and the Doppler-Drift Mode with limited frequencies and ranges.

2.1   Maximum Amplitude Mode

The Maximum Amplitude Mode is used for recording of digital ionograms. For each of the 128 range bins of the more than 100 carrier frequencies the largest amplitude of the 24 possible channels is selected. The amplitude is recorded together with a status character, indicating the selected channel number. Since the signals arriving from different directions with different Doppler travel along different paths, they mostly have different travel time. Thus the maximum method does not suppress essential information.

In the contrary this differential method, selecting the strongest amplitudes, enhances the main features of the investigated propagation medium, as shown on the right side in Fig. 1. With frequency as the abscissa and range as ordinate the amplitudes (on the bottom) or the status characters (on top) form patterns from the numerical presentations as the third dimension (K. Bibl, 1974). Different features are clearly distinguishable simultaneously. While one area of reflection (showing large values of the status indicator on the top of the picture) moves toward the observation station, the older ionization, forming the lower pattern, with numerical values below 8, moves away. While the presence of the "4" bit (numbers between 5 and 7 or 13 and 15) indicates high Doppler speed, the numbers 1, 5, 9, 13 indicate one direction, 2, 6, 10, 14 another and the numbers 3, 7, 11 and 15 a third direction of the arriving echoes.

A different method of data presentation, the split-screen technique, is presented in Fig. 1a. Here two complementary data sets, echoes with ordinary and with extraordinary polarization, are presented in two separate ionograms. Splitting into several ionograms is possible by an on-line microcomputer (Fig. 2). On the bottom of the figure the total of the recorded data is presented first in the form of amplitude ionograms and above those as status ionograms. On top of these two ionograms the data are broken down into three practically independent amplitude ionograms which show echoes arriving from three different directions. Since the interference is split in the same way a substantial reduction in interference appearance is achieved that way. To increase the number of scanned directions the receiver antenna beam is looking into different directions in sequential ionograms which are corresponding to the left or the right side of Fig. 2. This is done to increase the number of reflection areas with the same range displayed simultaneously and to increase the sensitivity of the differential selection in the Maximum Amplitude mode which overcomes the limitations caused by the large beam width of the receiver antenna array. Thus the ionogram showing the vertical echo also includes echoes from directions not separated by the split screen method. Therefore the consecutive "vertical" ionograms appear somewhat different and must be further cleaned in the microcomputer to include only common echoes. Similarly two additional directions: north and south can be constructed by extracting echoes common in the NW and NE or SW and SE ionogram respectively. Thus it will be possible to construct false color ionograms indicating six different directions as six different colors plus overhead as white and still maintain amplitude and/or Doppler information as numbers. A third method is the suppression of unwanted echoes, as shown in Fig. 3. This method finds application mainly in automatic compression and analysis of large data series where one magneto-ionic component or oblique echoes should be suppressed (Fig. 4). But the switching between ionograms with and without suppression of specific echoes shows surprises even to experienced data analysts, specifically in the aurora region where oblique echoes are often interpreted wrongly. Thus the digital tagging of the echo properties is significant also for the manual data analysis as inputs for world-wide mapping.

2.2   Doppler-Drift Mode

In the Doppler-Drift Mode a full complex spectrum analysis is executed in real time during the measurement. The build-up of the spectra can be observed for any and all of the 24 independent channels by the programmable test features. Guided by the survey provided by the Maximum Amplitude Mode six frequencies and ranges can be chosen for the scanning of four antennas simultaneously. Rather than processing a multitude of frequencies and ranges, the signals from up to 24 antennas are spectrum analyzed simultaneously. This interlaced spectrum analysis is necessary if low Doppler frequencies have to be studied and the propagation conditions provide barely consistent data during the integration period. In contrast to the Fast Fourier Transform procedure used in most computers our Direct Discrete Fourier Transform algorithm with Hanning weighting by averaging the spectral phase function provides a continuous consistency check of the data. Fig. 5 shows that the complete multi-dimensional spectrum analysis is executed while the data are digitized as quadrature samples of the Intermediate Frequency (IF).

3.   APPLICATION

A wide field of actual and possible applications for this instrument can be envisioned. The first system has been used to study the equatorial spread-F phenomenon in the ionosphere which heavily affects satellite-ground communication and navigation up to several GHz during many nights. Similar phenomena are studied in the aurora region of the ionosphere. We further applied the Digisonde to measurements of the sea-state of the oceans by direct and ionospherically reflected scatter and bistatic radio propagation experiments.

3.1   Gravity Waves and Fine Structure in the Ionosphere

Incidence angle measurement on spectrum-analyzed monostatic and bistatic pulse radio signals have shown that the structure of the ionosphere is multidimensional. Only rarely can the ionosphere be considered a plane reflector with an effective reflecting surface of the size and shape of the first Fresnel zone. In most cases the surface of constant electron density is two-dimensionally curved.

Therefore it is not always possible to find an area of perpendicularity but sometimes more than one perpendicular area can be found. The requirement of perpendicularity is related to the requirement of constant phase by the Fresnel condition which permits coherent integration of all contributions within the Fresnel zone.

Although spectrum analysis diminishes the area which can contribute to a coherently integrated signal it does simultaneously ease the condition of perpendicularity. Under the assumption of an almost constant drift of all irregular structure over the surface of constant electron density the spectrum analysis cuts out a band from this surface. The width of the band is determined by the drift speed and by the spectral resolution to comprise all reflection points with the same Doppler frequency. The length of the band is given by the Fresnel condition and is only extensive if the surface is perpendicular at least in the direction along the band (which is oriented perpendicular to the drift velocity).

But the perpendicularity requirement across the band is substantially relaxed because a change by one-half wavelength in phase path can be admitted for the width of the reflecting surface band if the roughness of the surface is sufficient to produce specular reflection. Under reasonable assumptions of drift speed and spectral resolution the reflecting surface band has a width in the order of 500 m (for F-region heights) which permits coherent addition of returns from all points of the surface if the inclination of the surface is less than 6° at 3 MHz probing frequency. Similar deviations from perpendicularity are permitted in the F-region since some of the changes in parameters compensate each other.

This Doppler-induced quasi-perpendicularity condition makes a large part of the constant electron density surface visible simultaneously and permits determination of its three-dimensional structure and motion at least in the time sequence of the "sky maps" which indicate the locations of all the reflection areas for all Doppler frequencies present at the sampling time (Fig. 6).

In transionospheric transmissions from satellites and reflections from targets fading, scintillation and positioning errors are caused by multimode propagation. Although the spacing of the different propagation paths is small compared with those of the vertical or oblique reflection case, effects of the multimode propagation might become important since higher accuracy for the incidence angle determination is required. Not always does the higher operation frequency compensate for the more stringent accuracy requirements. Therefore a good three-dimensional model is necessary for the correction of incidence angle errors. It can be produced by either multi-antenna complex spectral analysis of known satellite signals or by extrapolation from vertical sounding experiments not too far (<500 km) from the subionospheric point of the expected satellite propagation path.

3.2   Sea-Surface Waves

In March 1973 a Digisonde was used for the radio Doppler probing of the ocean surface in Eglin, Florida (Fig. 7). At a radio frequency around 6 MHz the energy scattered back showed Doppler offsets of ±0.25 Hz. These observations are in good agreement with the theoretically predicted Bragg scatter lines, but show many additional features and unexpected events. Nevertheless even the motion of the water parallel to the wave motion can be resolved.

3.3   Future Applications

The precision of the digital direct frequency synthesis, and the large antenna array permit accurate angular measurements for radio-interferometry in the frequency range of 20 to 40 MHz. Solar, planetary and galactic sources can be studied with this system. A combined acoustic-electromagnetic sounding of the non-ionized atmosphere is very promising. Acoustic scanning in medical and material research requires only little modification. Scanning of the sea-bottom (after conversion to acoustical waves) and underground radio communication and structure research should also be possible with this system.

We are developing a prototype for a topside digital ionosonde with very low output data rate (300 bits/sec). Such a system can also be used as a unmanned station on an island or a buoy in the ocean, on-board of a ship or in the arctic or antarctic. This sounder will broadcast the significant information of the preceding ionogram during the following ionogram to another Digisonde station in a distance of up to 3000 km for remote recording via an ionospheric propagation path (K. Bibl and B. W. Reinisch, 1976). This method has the advantage that the ionospheric conditions at the location of the ionospheric reflection can be monitored simultaneously. Data from several stations can be recorded simultaneously. Such a system can form an emergency radio propagation prediction network in case that satellite communication is interrupted. But for normal conditions simpler and more reliable satellite links can be used for collecting the low rate data from remote unmanned Digisonde stations.

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46-4
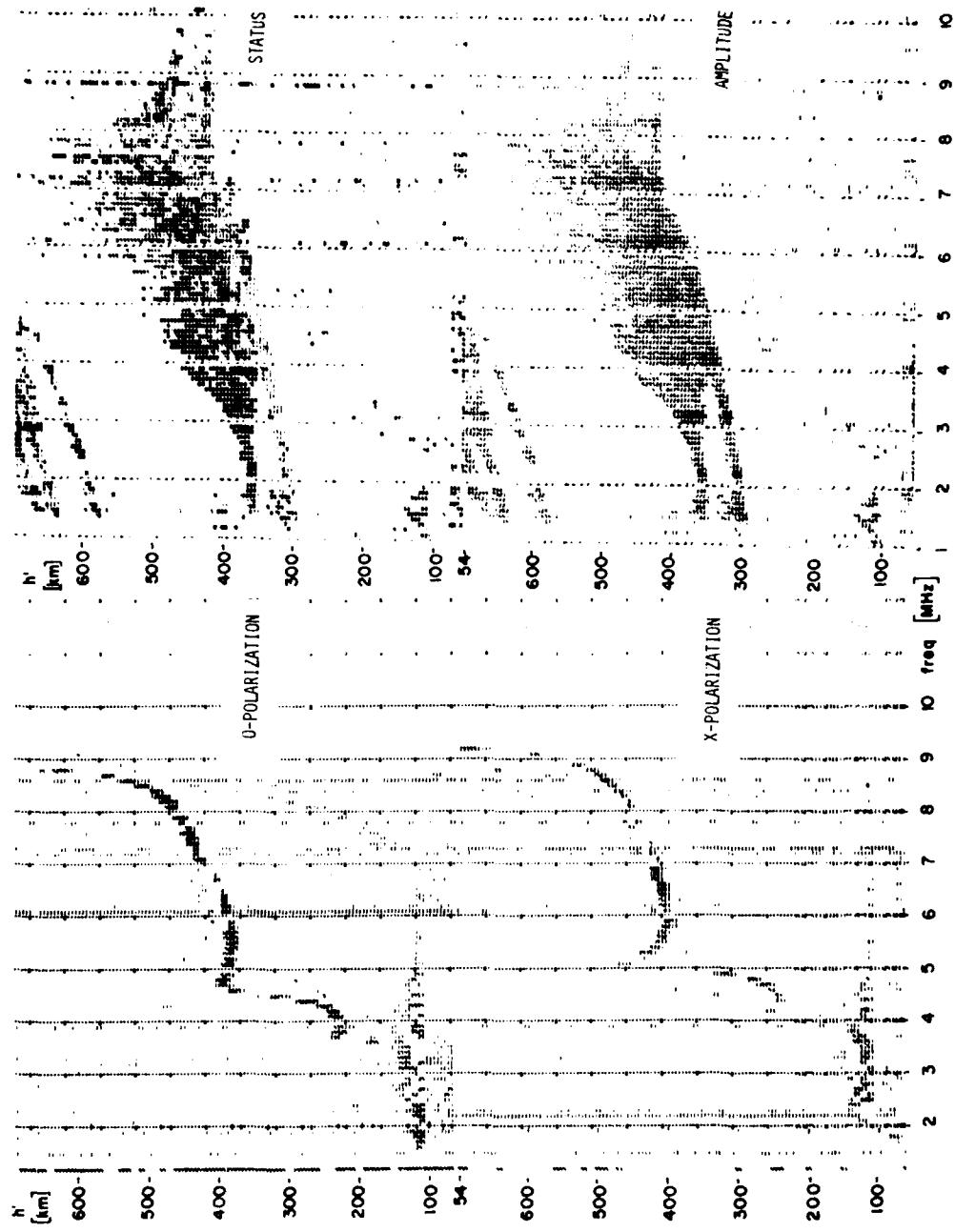
Fig. 1b AMPLITUDE, AZIMUTH AND DOPPLER

Fig. 1a SPLIT IONOGRAM

COMPUTER-SPLIT DIRECTIONAL IONOGRAMS   KWAJALEIN 21 MAR 78
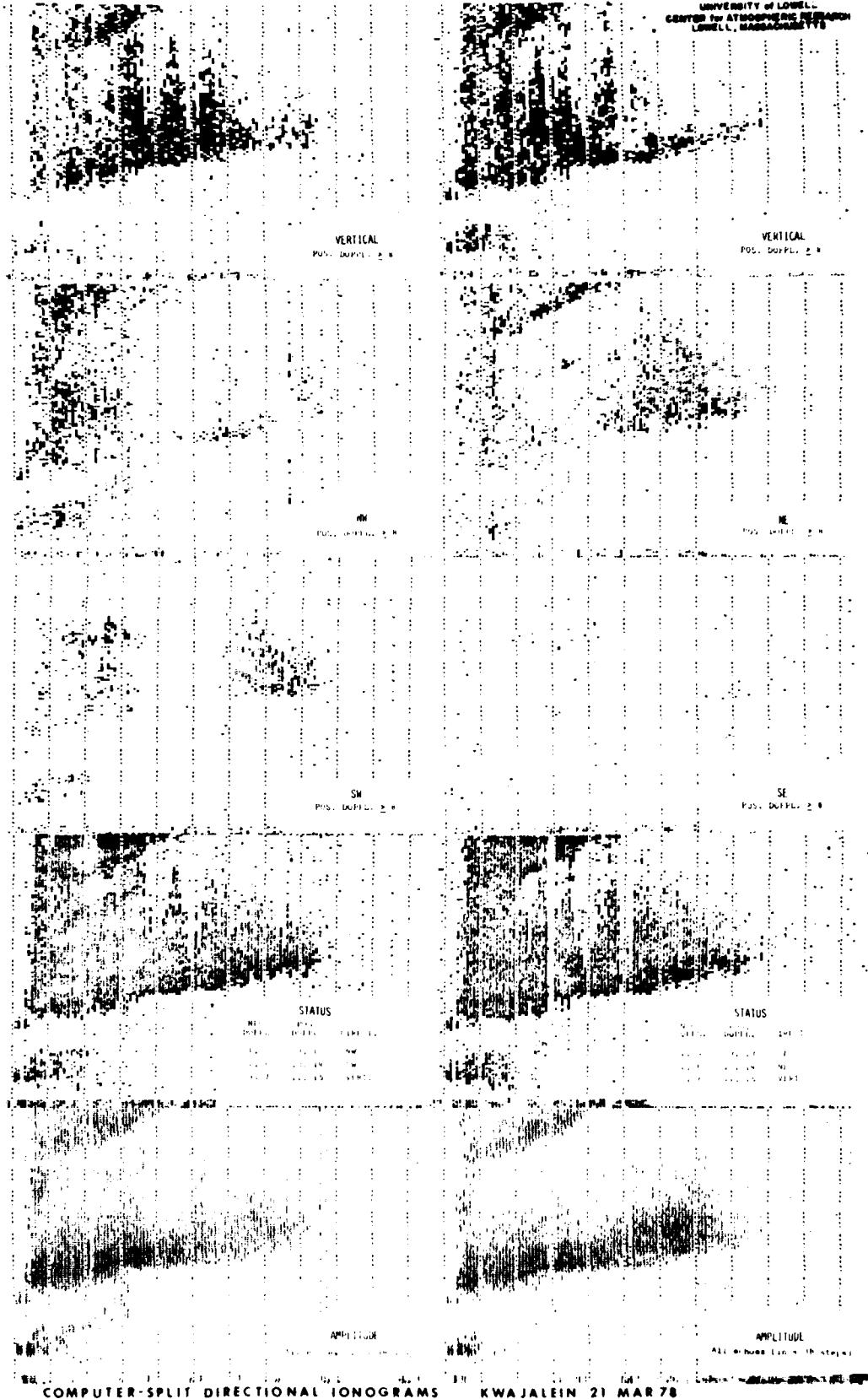
Fig. 2 COMPUTER-SPLIT DIRECTIONAL IONOGRAMS

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GOOSE BAY, LABRADOR AFGL 3 DEC 78
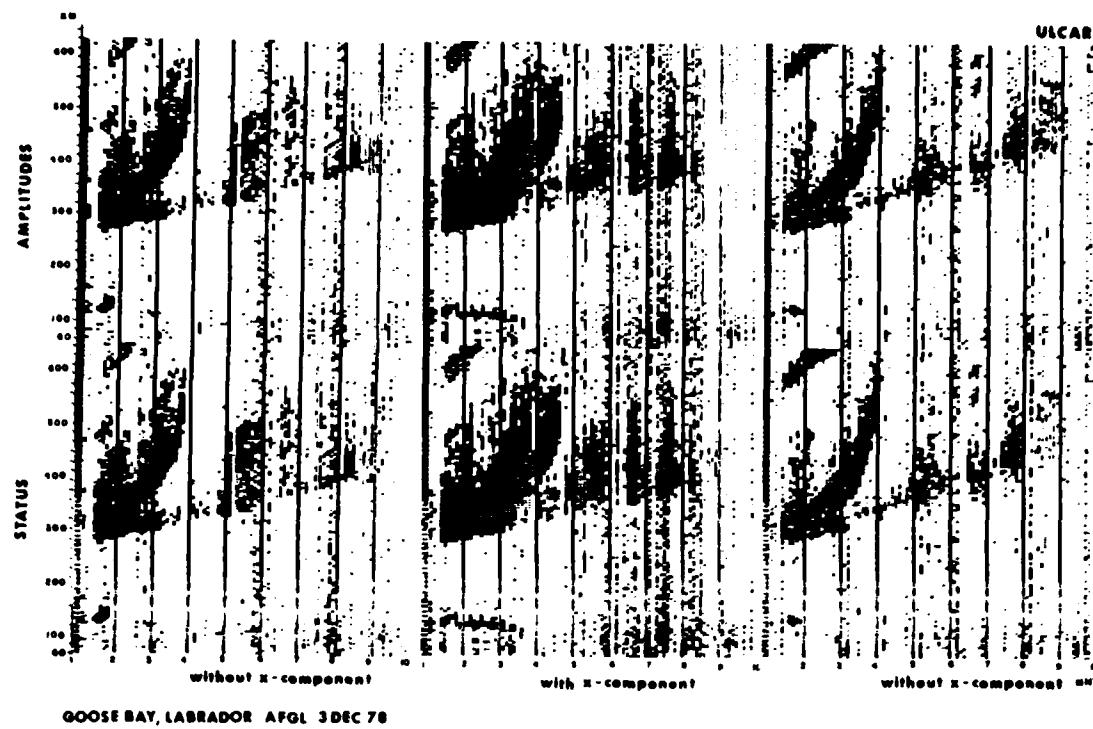
Fig. 3   DIGITAL SUPPRESSION OF THE EXTRAORDINARY COMPONENT
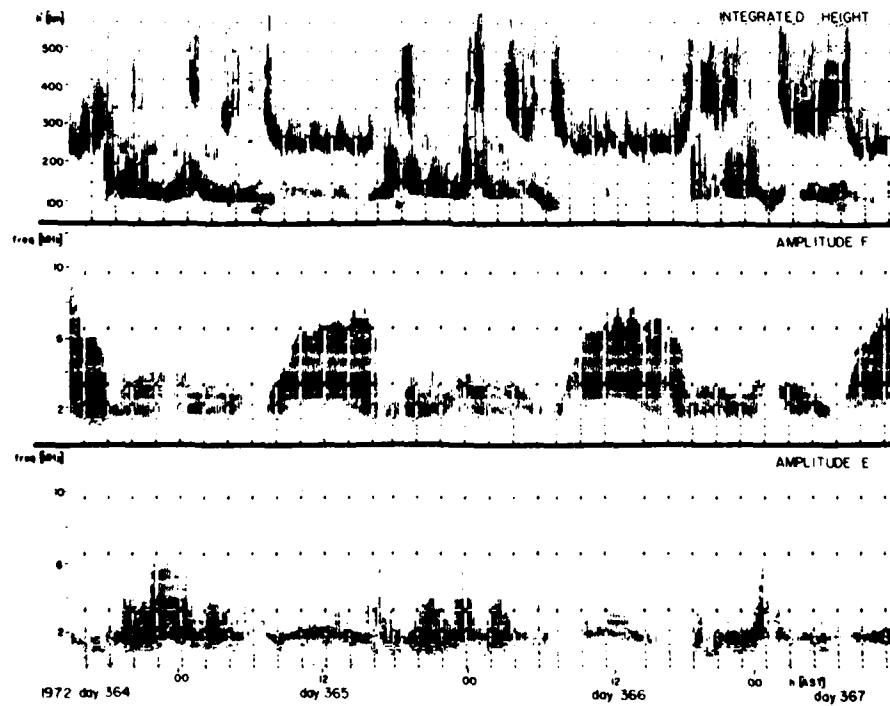
AIR6
VERTICAL IONOGRAMS
GOOSE BAY, LABRADOR

Fig. 4
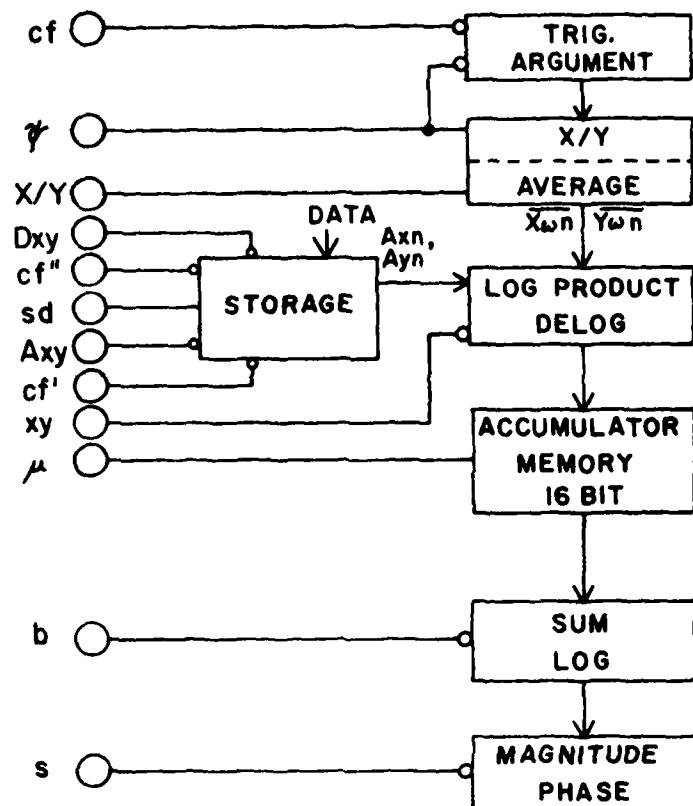
107

$$\sum_{n}^{n} (Axn \cdot \overline{X\omega n} + Ayn \cdot \overline{Y\omega n}) = R^{+}\omega$$
$$\sum_{n}^{n} (Ayn \cdot \overline{X\omega n} - Axn \cdot \overline{Y\omega n}) = I^{+}\omega$$
$$\sum_{n}^{n} (Axn \cdot \overline{X\omega n} - Ayn \cdot \overline{Y\omega n}) = R^{-}\omega$$
$$\sum_{n}^{n} (Ayn \cdot \overline{X\omega n} + Axn \cdot \overline{Y\omega n}) = I^{-}\omega$$

REAL-TIME SPECTRUM ANALYSIS

Fig. 5

108
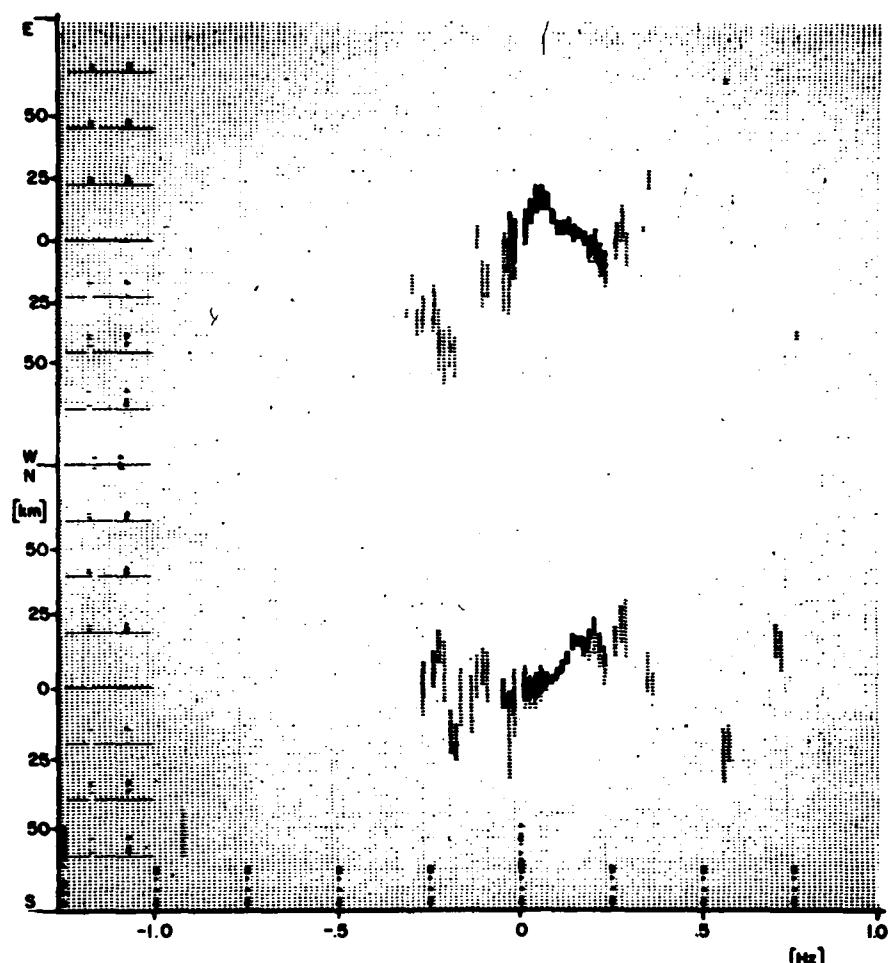
DAASM DISPLAY
4 APRIL 72
EGLIN, FLA.
2.01 MHz—105 km

Fig. 6
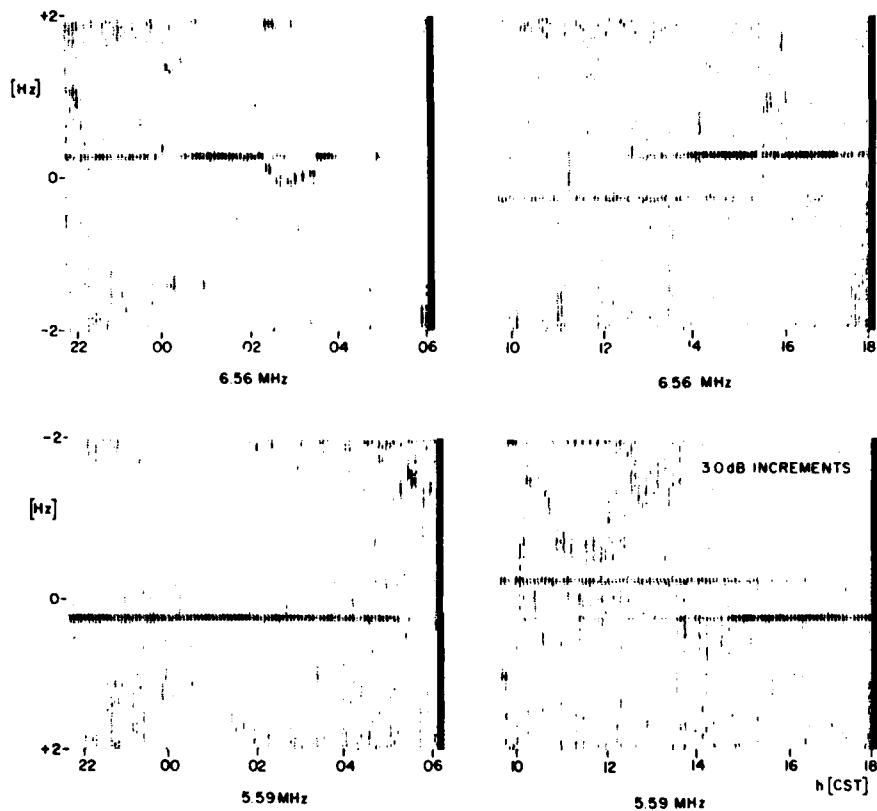
SEASCATTER DOPPLER SPECTRUM
17-18 MARCH 1973
EGLIN, FLA.

Fig. 7

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CENTER FOR ATMOSPHERIC RESEARCH
Lowell, Massachusetts

REAL-TIME SPECTRA FOR INCIDENCE ANGLE SPREAD IN

MULTIPATH PROPAGATION CAUSED BY IONOSPHERE

by

Bodo W. Reinisch

Klaus Bibl

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REAL-TIME SPECTRA FOR INCIDENCE ANGLE SPREAD IN
MULTIPATH PROPAGATION CAUSED BY IONOSPHERE

by

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Abstract

Electromagnetic signals from a set of receiving antennas are individually processed, the complex spectrum is determined for each antenna j, $F_{jl} = \{A_{jl}, \phi_{jl}\}$. The spectral composition is resolved in 128 lines, i.e. l goes from -63 to +64. Cross-correlation of the frequency spectra and subsequent transformation into the spatial domain finds the incidence angles of each spectral component. The frequency-wave-number power density

$$P_{kl} = \sum_j \sum_{j'} F_{jl} \, F_{j'l}^* \, exp \; i \; \underline{k} \cdot (\underline{a}_j - \underline{a}_{j'})$$

determines the power and spectral content for each "looking vector" $\underline{k}$. Actually, $\underline{k}$ is the wave vector and the vectors $\underline{a}_j$ point to the individual antennas. This method separates the multipath components for ionospherically reflected radio waves and for satellite-to-ground signal paths.

1.0 INTRODUCTION

Radio waves are characterized by amplitude, phase, wave vector, wave polarizaiton, frequency and signal travel time. All these wave parameters are measured in real-time in a new digital ionosonde, the Digisonde 128PS. We want to concentrate here on the measurement of the Doppler shifts and the

angular spectra of radio signals that are reflected at the earth's ionosphere. The same technique is applicable, however, for transionospheric propagation.

Direction finding for dekameter waves is not an easy task in case of multiple sources, or multiple paths. Unless very large receiving antenna arrays are used the beam width is normally too wide to resolve neighboring paths. It is easy to visualize that radio signals reflected from a moving ionosphere will have a Doppler frequency that is proportional to the carrier frequency, the speed of the reflector, and the angle between the velocity vector $\underline{v}$ and the electromagnetic wave vector $\underline{k}$, $d = (1/\pi)\ \underline{k}\cdot\underline{v}$.

2.0 PATH SEPARATION BY DOPPLER MEASUREMENT

A transmitted radio wave illuminates a certain area of the ionosphere for vertical (monostatic) as well as for oblique (bistatic) sounding. Reflection occurs at several points or areas in the ionosphere, depending on the structure of the ionization, in such a way that signals will propagate along different paths carrying slightly different Doppler frequencies (Bibl et al, 1975). Figure 1 illustrates the geometry for the case of monostatic operation. Echoes from two neighboring points differ in their Doppler frequency by

$$\delta d = \frac{1}{\pi}\ k\ v\ \delta(\cos\psi)$$

where ψ is the angle between $\underline{v}$ and $\underline{k}$. Using the angles of Figure 1, where $\underline{v}$ was assumed to be horizontal, we write:

$$\cos\psi = \sin\theta\ \cos(\phi-\phi')$$

and

$$\delta(\cos\psi) = \cos\theta\cos(\phi-\phi')\delta\theta - \sin\theta\sin(\phi-\phi')\delta\phi.$$

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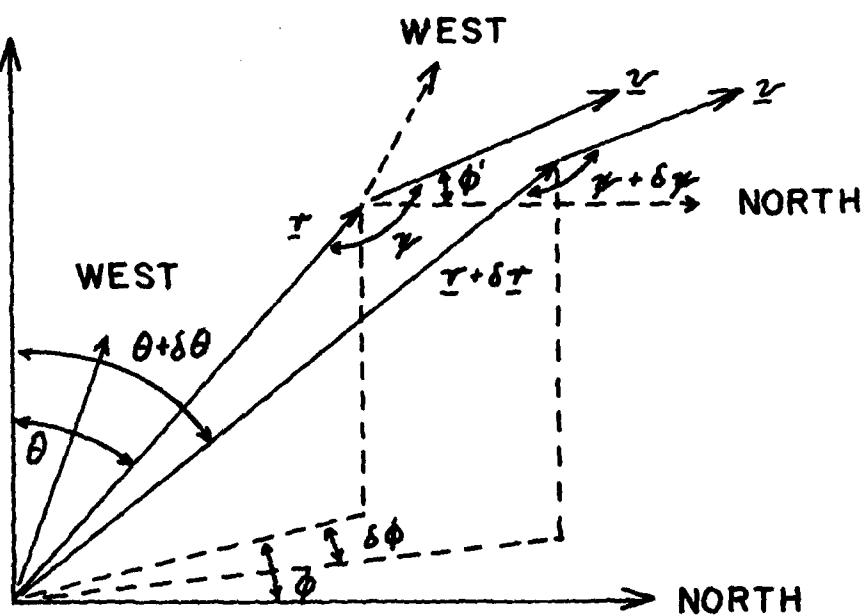
DOPPLER GEOMETRY

FIGURE 1

When looking in the direction of the velocity vector, i.e.
$\phi = \phi'$, the variation in Doppler becomes:

$$\delta d = \frac{1}{\pi} k \, v \, \cos\theta \, \delta\theta \ .$$

For a given spectral resolution δd the angular resolution is
therefore:

$$\delta\theta = \frac{\pi \ \delta d}{k \ v \ \cos\theta} = \frac{\lambda \ \delta d}{2 \ v \ \cos\theta}.$$

Substituting some typical values for the Digisonde, $\delta d = 0.03$
Hz, $\lambda = 50$ m (6 MHz) and $v = 100$ m/s, one obtains for small
angles θ

$$\delta\theta = 7.5 \cdot 10^{-3}$$

corresponding to a source separation of 1.5 km in 200 km alti-
tude. By storing the energy from such closely spaced sources
in different spectral channels we can determine their location
even in the presence of other strong sources with different
Dopplers. When looking in the direction of $\underline{v}$, sources with
$\delta\theta = 0$ separated by a small angle $\delta\phi$ have the same Doppler and
can only be resolved by a sufficiently large antenna aperture.

3.0 DISCRETE FOURIER TRANSFORM

To obtain the Doppler shifts, the Digisonde converts
the radio signals from an array of receiving antennas to an
intermediate frequency of 255 kHz, digitizes in the quadrature
method the logarithmically compressed IF signal and applies a
discrete Fourier transform. The complex transform is calcu-
lated for each of the up to 24 antenna signals by making
direct use of the quadrature samples X and Y. In general, the
receiving antennas are scanned at a rate of 24 per quarter
second. For the j-th antenna the transform can be written:

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$$F_{j\ell} = \frac{1}{T} \sum_n [X_j(n\Delta t) + iY_j(n\Delta t)] \exp{-i(2\pi\ell\, n\Delta t/T)}$$

$$= \frac{i}{T} \sum_n [X_{jn} \cos\beta_{\ell n} + Y_{jn} \sin\beta_{\ell n}]$$

$$+ \frac{i}{T} \sum_n [-X_{jn} \sin\beta_{\ell n} + Y_{jn} \cos\beta_{\ell n}]$$

where ℓ is the Doppler line, T is the length of the time window and $\beta_{\ell n} = 2\pi\Omega\, n\Delta t/T$. While the initial multiplication of the time samples with the trigonometric functions is carried out in the logarithmic domain, the final summation is, of course, performed in the linear domain. Hanning weighting is applied in the frequency domain by averaging three adjacent spectral lines with weights of 1-2-1. The result of the 24 channel Fourier analysis are 24 number arrays of the form

$$j = 1, \ldots, 24$$

$$F_{j\ell} = \{M_{j\ell}, \phi_{j\ell}\}$$

$$- 63 \le \ell \le 64$$

where $M_{j\ell}$ are the logarithmic spectral amplitudes (64 dB range in 1 dB increments, or 32 dB with 1/2 dB) and $\phi_{j\ell}$ are the corresponding phases with a resolution of $2\pi/512$.

For the Digisonde operation it was necessary to develop a method of calculation that requires no extra time beyond the last time sample, since between the time windows we allow only one second for recording of the spectra on magnetic tape for later computer processing. Directly following digitization the quadrature pair is multiplied by all 128 time-adjusted values of $\cos\beta_{\ell n}$ and $\sin\beta_{\ell n}$, respectively, and the 256 spectral samples thus obtained are added to the previous 256 samples. After the last time sample the final four sums $\sum_n X_{jn} \cos\beta_{\ell n}$, $\sum_n X_{jn} \sin\beta_{\ell n}$, $\sum_n Y_{jn} \cos\beta_{\ell n}$ and $\sum_n Y_{jn} \sin\beta_{\ell n}$ are suitably combined for each j-channel to form the real and imaginary parts of the spectra.

The complex Fourier spectra are converted in real-time into an angular power spectrum. The aim is to find for each Doppler component the corresponding incidence angle, or possibly several angles if wave energy of the same Doppler frequency is arriving from different directions. In our initial approach we limited ourselves to four receiving antennas for the real-time processing. But this limit was arbitrary and there is no difficulty in expanding it to 12 antennas.

For a given angle of arrival, specified by the wave vector $\underline{k}$, the frequency-wavenumber power density is calculated (Sales et al, 1975):

$$P_{\ell k} = \sum_{j} \sum_{j'} F_{j\ell} \, F_{j'\ell}^{*} \, \exp{-i\underline{k}\cdot(\underline{a}_j - \underline{a}_{j'})}$$

where $F_{j\ell}$ is the Fourier spectrum for antenna j, and the $\underline{a}_j$'s are the antenna distance vectors. By substituting for

$$F_{j\ell} = A_{j\ell} \, \exp{i\,\phi_{j\ell}}$$

the power density can be written as

$$P_{\ell k} = \left| \sum_{j} A_{j\ell} \, \exp{i(\phi_{j\ell} - \underline{k}\cdot\underline{a}_j)} \right|^2$$

Depending on the observational program, monostatic, bistatic or transionospheric, the receiving array will be arranged correspondingly and an adequate format must be selected to present the angular spectra. For the case of vertical sounding we expect echoes from within a cone of about 90° solid angle. Each direction is represented by its x, y coordinates with $x = r \cos\phi \sin\theta$ and $y = r \sin\phi \sin\theta$, r is the echo range. The Digisonde calculates the power densities for equal increments in x and y. These increments are selected as function of r. A sky map of 40 × 40 points is generated this way.

So far, each x, y point contains a complete spectrum $P_{\ell k}$. A sorting algorithm finds for each spectral component the x, y position with the maximum power density. The resulting sky map displays, therefore, the power density together with the spectral component number ℓ. An example of a sky map is shown in Figure 2 where the reflection points are connected by an arrowed line pointing in the direction of increasing Doppler frequency. The sorting algorithm is essentially a differential method in that it searches for a maximum in spectral density as function of x and y. This overcomes the limited resolution of the array directivity. As a further improvement it is considered to search for more than one discrete maximum for each spectral component.

5.0 ACKNOWLEDGEMENT

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G. S. Sales, J. I. Videberg and R. Varad, DAASM Project - High Latitude Aircraft HF Propagation Experiment, Scientific Report, AFCRL-TR-75-0290, Environmental Research Paper No. 516, Air Force Geophysics Laboratory, Hanscom Air Force Base, Bedford, Massachusetts 01731 (1975).

HEIGHT 112 KM

FREQUENCY 2.0 MHz
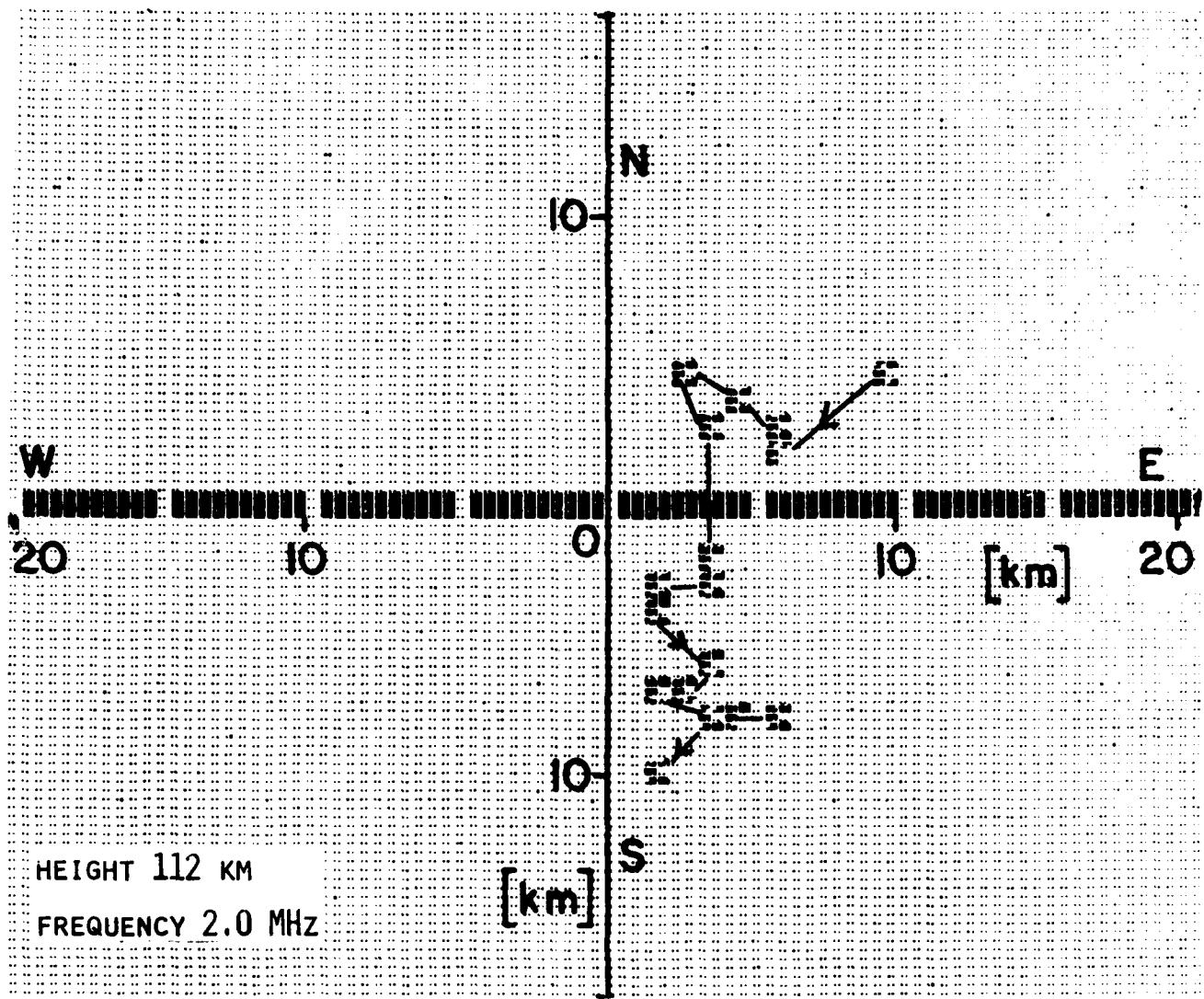
SKY MAP

FIGURE 2

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Lowell, Massachusetts

DIGITAL PREPROCESSING, ON-LINE PROCESSING

AND DISPLAY OF MULTIPARAMETER TRANSMISSION DATA

by

Klaus Bibl

Bodo W. Reinisch

DIGITAL PREPROCESSING, ON-LINE PROCESSING

AND DISPLAY OF MULTIPARAMETER TRANSMISSION DATA

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1.0 INTRODUCTION

Simultaneous recording and display of all parameters of a radio wave propagated through a highly dispersive medium is possible with digital processing. For the measurement of the structure and the motion of the dispersive medium and for a full analysis of the radio propagation properties of communication links digital radio sounders can be employed with pulsed carrier frequencies scanning in steps through a large frequency band.

Frequency scanning adds an extra parameter to the wave characteristics of a conventional Radar system: amplitude, phase or Doppler frequency, range, incidence angle and polarization.

2.0 DATA PREPROCESSING

As a scientific instrument, but useful for many operational tasks, we have developed a digital ionosonde which uses a large antenna array in a scanning or a beam-forming mode. The Digisonde 128PS (K. Bibl and B. W. Reinisch, 1977) integrates the echoes coherently at many Doppler frequencies simultaneously for all antennas or all beam-directions. Echoes from 24 antennas can at once be spectrum analyzed in 128 coherent channels, or 16 spectral lines can be monitored for

128 range bins. Many other combinations of ranges, frequencies, polarizations, spectral channels and incidence angles can be processed simultaneously. Using the time between the transmitted pulse to measure complex spectrum amplitudes in up to 256 range bins (time sectors) requires a very fast on-line spectrum analyzer. The Processing Controller of the Digisonde forms the products between the sine and cosine samples of the high frequency (HF) signal and the phase function of three averaged spectral lines at a 1 MHz rate during the measurement. But such an amount of data is too large for any institute to handle on a continuous basis. We therefore operate the system in one of two compression modes.

3.0 MAXIMUM AMPLITUDE MODE

The Maximum Amplitude Mode is used for recording of digital ionograms. For each of the 128 range bins of the more than 100 carrier frequencies the largest amplitude of the 24 possible channels is selected. The amplitude is recorded together with a status character, indicating the selected channel number. Since the signals arriving from different directions with different Doppler travel along different paths, they mostly have different travel time. Thus the maximum method does not suppress essential information.

In the contrary this differential method, selecting the strongest amplitudes, enhances the main features of the investigated propagation medium, as shown in Fig. 1. With frequency as the abscissa and range as ordinate the amplitudes or the status characters form patterns from the numerical presentations as the third dimension. Different features are clearly distinguishable simultaneously. While one area of reflection (showing large values of the status indicator on the top of the picture) moves toward the observation station, the

123
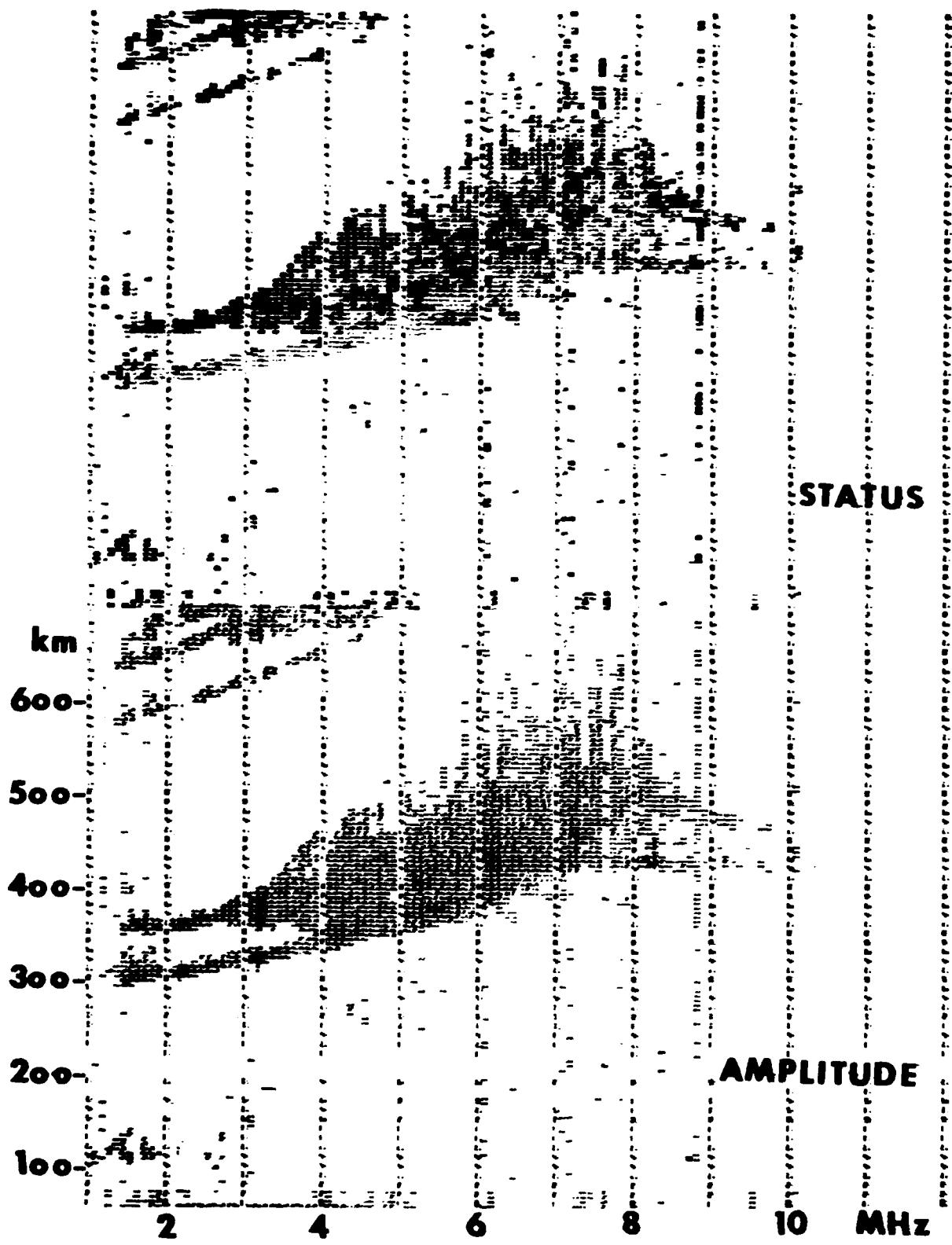
Fig. 1   AMPLITUDE, AZIMUTH AND DOPPLER AS
FUNCTIONS OF RANGE AND FREQUENCY

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older ionization, forming the lower pattern moves away. In
Fig. 2 the echo trace with ordinary polarization is charac-
terized by the "4" bit in the status character, while the
other bits indicate the Doppler speed (numbers larger than 8
indicate positive Doppler).

4.0   DOPPLER-DRIFT MODE

In the Doppler-Drift Mode a full complex spectrum
analysis is executed in real time during the measurement.
The build-up of the spectra can be observed for any and all of
the 24 independent channels by the programmable test features.
Guided by the survey provided by the Maximum Amplitude Mode
six frequencies and ranges can be chosen for the scanning of
four antennas simultaneously. Four decimal digits in frequen-
cies, three decimal digits in range and one octal digit in re-
ceiver gain can be independently selected. All this informa-
tion plus 20 additional operational parameters (pulse repeti-
tion rate, pulse width, antenna selection and sequences, num-
ber of samples, etc.) are stored together with date and time
in an 80 character preface which is repeated for each record
and updated for every measured case. Rather than processing
a multitude of frequencies and ranges, the signals from up to
24 antennas can be spectrum analyzed simultaneously. This
interlaced spectrum analysis is necessary if low Doppler fre-
quencies have to be studied and the propagation conditions
provide barely consistent data during the integration period.
In contrast to the Fast Fourier Transform procedure used in
most computers our Direct Discrete Fourier Transform algorithm
with Hanning weighting by averaging the spectral phase func-
tion provides a continuous consistency check of the data.
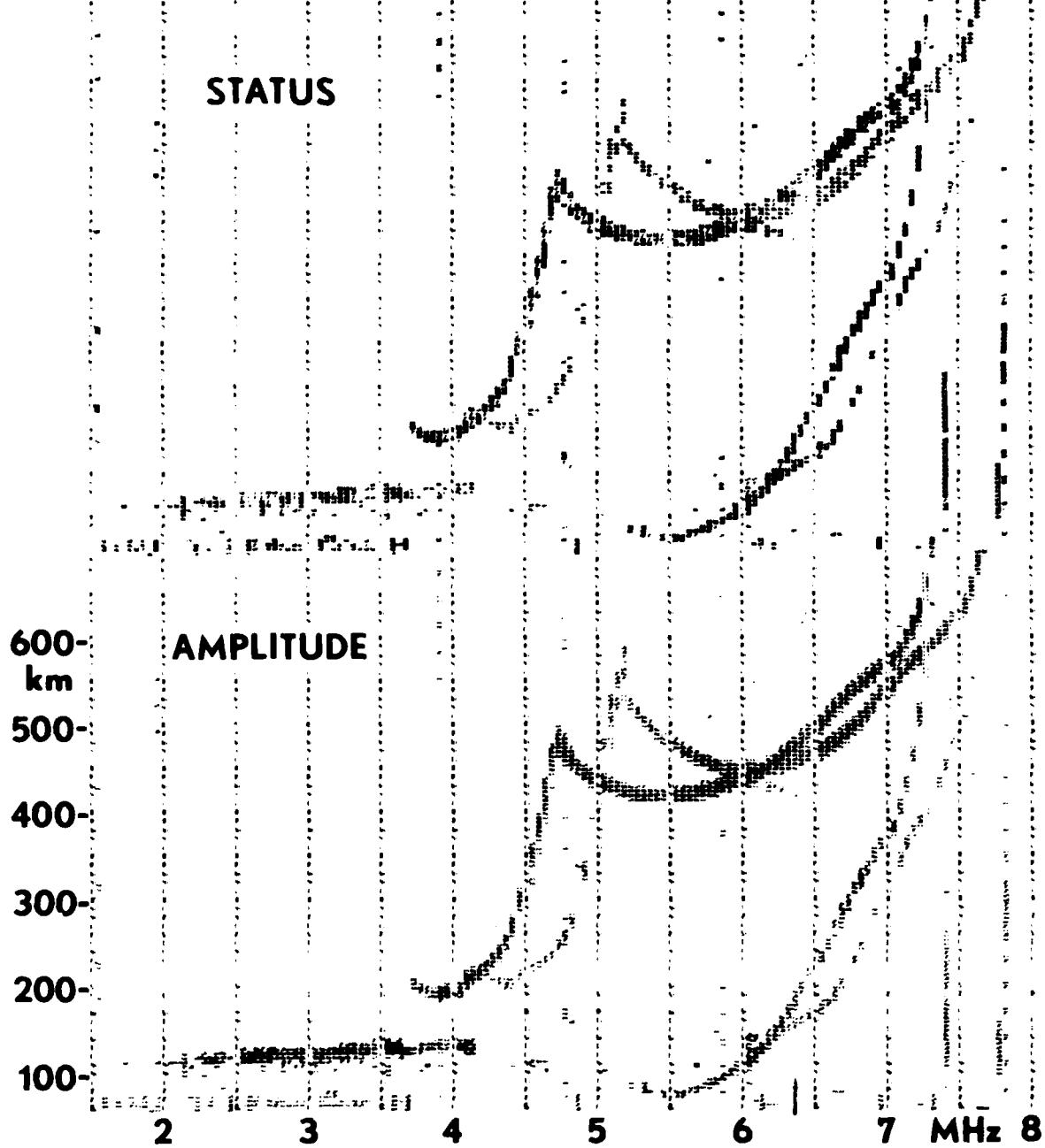
Fig. 2 AMPLITUDE, POLARIZATION AND
DOPPLER AS FUNCTIONS OF RANGE
AND FREQUENCY

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5.0 DIGITAL DISPLAY

The three-dimensional digital display, as shown in
Figures 1 and 2, is an important feature of our system. Spe-
cial fonts for the numbers have been introduced (J. Patenaude
et al, 1973) to make the number of dots of which they consist
proportional to the value of the number. Dependent on the
importance of a parameter for the investigation, the selection
of the respective bits in the status flags can be chosen to
emphasize specific features: like polarization, high Doppler
rate or special incidence directions. Areas with similar num-
bers form patterns and, with some training, more than three
dimensions can be visualized, avoiding the false color presen-
tations which are so expensive to reproduce and difficult to
interpret.

6.0 ON-LINE PROCESSING

With the help of special-purpose circuitry many pro-
visory analyses can be executed on-line, like the selection of
the important parameters for display, the measurement of in-
cidence angles from the Doppler phase-differential between
the different antennas, the profile and the fine structure of
the dispersive propagation medium and an interactive terminal
for display and programming. Because of the limited speed of
a mini-computer an adequate formatting of the raw data, in-
cluding full information of all operational parameters in a
preface, is a precondition for its successful and flexible
use as a sequential on-line processing device.

7.0 APPLICATION

We see a wide range of actual and possible applications for this instrument.

At this time the first system is used to study the equatorial spread-F phenomenon in the ionosphere which heavily affects satellite-ground communication and navigation up to 1000 MHz during many nights.

Similar phenomena are studied in the aurora region of the ionosphere. We further applied the Digisonde to measurements of the sea-state of the oceans by direct and ionospherically reflected scatter and bistatic radio propagation experiments.

The precision of the digital direct frequency synthesis and the large antenna array permits accurate angular measurements for radio-interferometry in the frequency range of 20 to 40 MHz. Solar, planetary and galactic sources can be studied with this system.

A combined acoustic-electromagnetic sounding of the non-ionized atmosphere is very promising. Acoustic scanning in medical and material research requires only little modification. Scanning of the sea-bottom (after conversion to acoustical waves) and underground radio communication and structure research should also be possible with this system.

8.0 ACKNOWLEDGEMENT

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EQUATORIAL SPREAD F OBSERVATIONS USE INCIDENCE ANGLE

AND DOPPLER MEASUREMENTS

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As part of DNA's Equatorial Wideband Program ground-based
ionospheric observations are conducted at Kwajalein, Marshall
Islands, with a new ionosonde, the Digisonde 128PS. To analyze
the spread F phenomenon it is necessary initially to inspect
the entire ionogram rather than relying on single frequency,
single range measurements. By rotating the beam of the re-
ceiving antenna array from NW to SW to SE to NE and to verti-
cal for each transmitted frequency we found a complicated
angular pattern. The main F-trace is often composed of ver-
tical echoes, while the spread echoes can be vertical and
oblique. In some cases the majority of the spread echoes
come from overhead, i.e. from within a cone of $5°$, and the
observed range spread of several hundred kilometers can only
be explained by deep holes in the bottom-side F-region and
multiple scatter. More frequently, the spread echoes simul-
taneously arrive from several directions (the antenna beam is
$15°$ off vertical), for example, from NF and SW for the high
frequencies (8 MHz) and from NW for the lower frequencies
(2 MHz). The sign of the signal doppler shifts indicates the
direction of motion of the reflecting irregularities. Several
case studies are discussed.

DIGITAL IONOSPHERIC SOUNDING WITH DOPPLER MEASUREMENTS
AND DIRECTION FINDING

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A new type of ionosonde, the Digisonde 128PS, presently
in operation at Kwajalein, Marshall Islands, and aboard an
aircraft, collects new data previously not available. All
characteristic parameters of the ionospheric radio echoes are
measured to extract the maximum information on the ionosphere.
The system measures the following signal parameters: complex
spectrum, i.e. spectral amplitudes and phases, angle of ar-
rival, polarization and, of course, group travel time. System
operation alternates between two complementary modes of ob-
servation, (1) ionograms and, (2) drift-doppler measurements.
A small computer postprocesses the data and generates sky
maps from the drift-doppler observations and electron density
profiles from the ionogram traces. Also, the computer can
control the sounding operation. Recordings from Kwajalein
and from the aircraft illustrate the system capabilities.